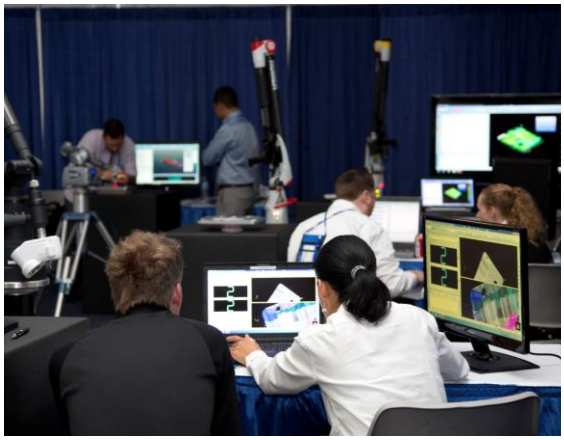
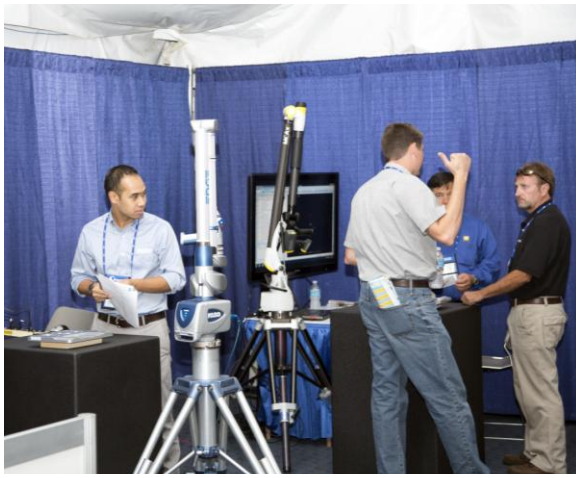


The Coordinate Metrology Society presents the

2013 CMSC Measurement Study Report

Non-Contact Scanning:
How Data is Affected by the Decisions We Make



29th Annual
Coordinate Metrology
Systems Conference

San Diego, CA
July 2013

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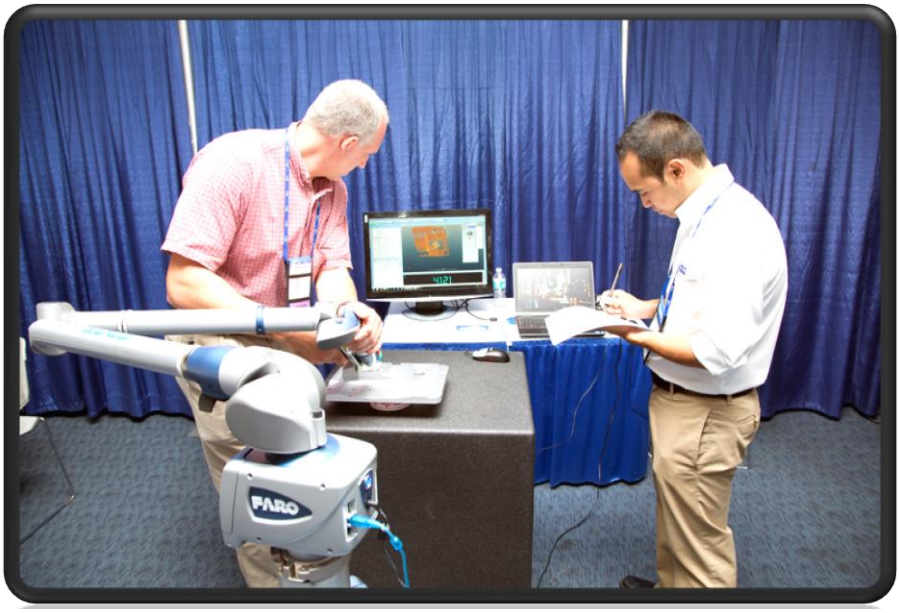

Cover Photography: Courtesy of the Coordinate Metrology Society, Photographer: Dirk Dursharme

The Coordinate Metrology Society

The Coordinate Metrology Society or CMS is the preeminent membership association for measurement professionals. The Coordinate Metrology Systems Conference is sponsored by the CMS, a professional society of users, service providers, and OEM manufacturers of high-precision, portable coordinate measurement solutions. The society membership assembles each year to get a first-hand look at the advancements and new developments in the use of portable measurement systems or software producing and using 3D coordinate data.

The CMS is driven by its charter to educate the membership about the utilization of 3D metrology systems (including traditional CMMs, laser trackers, photogrammetry, theodolites, laser projection systems, laser radar, non-contact scanning devices, GPS, and articulating arms) and their applications, such as reverse-engineering, tooling, inspection, metrology-assisted assembly, deformation analysis, automation and more.

The CMS community is encouraged to participate in many ways, from volunteering during the conference, running for a position on the Executive Committee, or serving on a sub-committee of the organization. To join the Coordinate Metrology Society or attend the yearly conference, contact the Registrar at registrar@cmsc.org. The organization's latest news and updates can be found at their www.CMSC.org.

Coordinate Metrology Systems Conference

Celebrating its 30th anniversary, the Coordinate Metrology Systems Conference (CMSC) is the world's premier event for Measurement Technology Professionals sponsored by the Coordinate Metrology Society. Established in 1984, the five-day annual conference is held each year at a different location, and attracts visitors from around the globe. CMSC is acclaimed for its comprehensive program of top-shelf white papers and applications presentations given by industry experts from science/research laboratories and manufacturing industries, such as aerospace, space hardware, automotive, shipbuilding, power generation, and general engineering. No other trade show rivals the high level of authoritative information provided by master users of portable metrology solutions for quality control, quality production, precision assembly, and more.

Coordinate Metrology Society Report

Non-Contact Scanning: How Data is Affected by the Decisions We Make

REPORT AUTHOR: Keith Bevan, National Physical Laboratory (NPL)
Edited by Belinda Jones, HiTech Marketing

Keith Bevan serves on the Certification Committee of the Coordinate Metrology Society. At the National Physical Laboratory (NPL), UK's National Measurement Institute, Keith is the Training Product Development Manager – Knowledge Services. NPL is one of the world's leading science and research facilities developing and applying the most accurate standards, science, and technology
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Email: keith.bevan@npl.co.uk | **Web:** www.npl.co.uk

Introduction and Project Overview

Following the success of the 2010, 2011 and 2012 measurement studies, the Coordinate Metrology Society commissioned another study for CMSC 2013. The purpose of the research was to evaluate how decisions made during and after measurement affect the final measurement result.

After months of planning for the event, an open measurement workshop was devised to invite conference delegates to participate in a 3D coordinate measurement study:

Non-Contact Scanning: How Data is Affected by the Decisions We Make

In the Measurement Study area of the Exhibition Hall, four stations accommodated participants undertaking practical tasks using a Portable Arm and a scanning system. In addition, up to six analysis stations were available to examine how decisions made while interpreting data can influence the results.

During the measurement study, participants had the option to participate in one or both of the measurement result and analysis tasks. Each participant was asked to:

- follow a prescribed series of requirements associated with the measurement or data provided.
- provide their level of experience and background.

All conference attendees were encouraged to participate in the daily practical testing activity, which provided a hands-on challenge for metrologists, regardless of their experience with portable scanning systems or knowledge and understanding of metrology. There were 120 sessions available per day, with sign-up sheets available for participants to reserve their slot.

"During the measurement study, an evaluation of the appropriateness of practical testing was undertaken incorporating key measurement strategy requirements and the behavior of coordinate metrologists."

The objectives of the 2013 measurement study were to also engage with the CMSC community in the practical methodology required to support certified operators and programmers. In addition, the participants were asked to evaluate the appropriateness of the tasks in relation to the CMS Certification development.

This year's measurement study was coordinated by the National Physical Laboratory (UK) and Metrologic, and assisted by members of the CMS Certification Committee, Coventry University, and volunteers from many equipment and software manufacturers.

MEASUREMENT WORKSHOP ACTIVITY

The activity took place over three days. Day 1 and 2 (July 23 and 24, 2013) were dedicated to the measurement study. The work culminated on Day 3 (July 23, 2013) with a workshop to review the results and to ascertain information about future measurement studies for CMSC.

The Measurement Study booth was developed around 10 stations — 4 stations equipped with articulated arms and scanning systems, and 6 data stations to analyze previously acquired measurement data.

Participants, application engineers, and observers were invited to sign up via the CMSC website or stop by the measurement study booth. Two persons (participant and Proctor) would be required at each station during each session. The roles of the participants, and proctors were defined in procedures and explained to the relevant person.

PROCEDURES

Participants

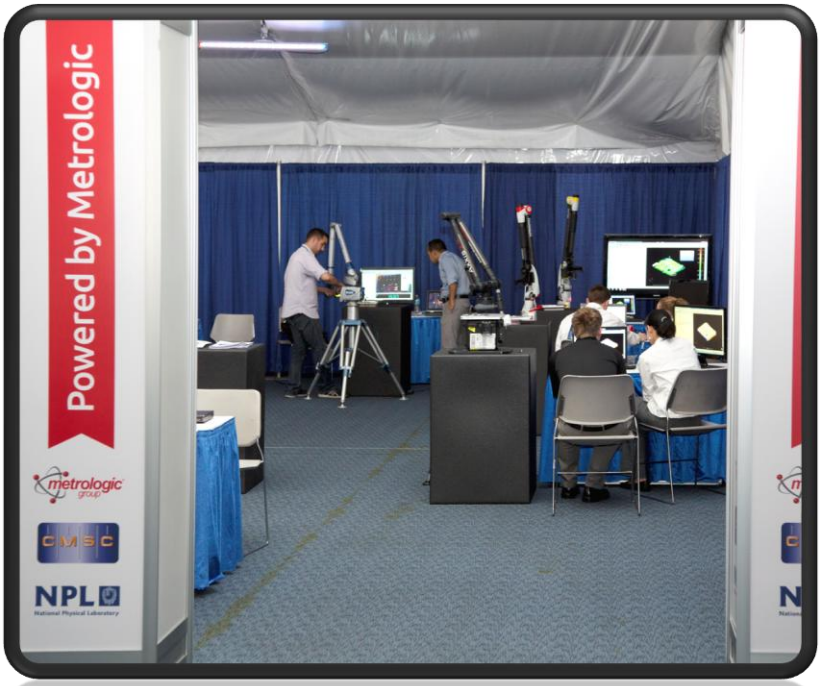
CMSC attendees could sign up on the PCMM station and/or Analysis stations. As a participant in the Measurement Study, they had the following responsibilities:

a) ***sign up*** for the Measurement Study online or at registration
b) ***show up*** at Measurement study booth 5 minutes before their scheduled time
c) ***receive*** a participant number and be directed to the appropriate station for a practical or analysis task
d) ***participate*** in the required task completing it within 30 minutes
e) ***complete*** both demographics and evaluation questions electronically during both the measurement tasks.

Proctors

Proctors supporting the Measurement Study had the following responsibilities:

a) ***attend*** a proctors training session on Monday, July 22, 2013
b) ***show up*** at the Measurement Study booth 5 minutes prior to agreed time slot
c) ***go*** to allocated station
d) ***obtain*** a participant number and enter on the observation sheet
e) ***identify*** the demographics category as indicated by the participant
f) ***invite*** the participant to start the task
g) ***observe*** the participant using the observation sheet provided. If guidance is required, the proctor indicates this on the form in the appropriate place
h) ***invite*** the participant to partake in the 2nd task
i) ***wait*** at the station in readiness for the next participant



Booth Moderators

a) ***meet*** and greet participants
b) ***pass*** demographics form to participants with making sure the form is allocated a number
c) ***monitor*** the tasks around booth and be available to assist when required
d) ***support*** participants when completing the feedback forms
e) ***enter*** data from the forms using turning point at the allocated station

Study Categories

The categories evaluated during the measurement study and workshop were:

- Demographics
- Observations
- Evaluation

Key characteristics were identified as a requirement to be observed during the measurement study.

- Pre-measurement
- Measurement planning
- Measurement
- Post measurement

Participants

The following criterion was identified so any conference delegates could participate in the measurement study. The participant's metrology skills fell into the one of the categories below, ranging from beginners to experts in the coordinate measurement.

- Beginner to measurement
- Beginner to portable measurement
- Some experience of portable measurement
- Experienced

Profile

As part of the measurement tasks, a series of questions would be asked of each participant to gauge a participant profile:

- Industrial sector
- Job role
- Age range
- Experience
- Frequency of taking measurements
- Participation in the 2012 measurement study
- Training

MEASUREMENT TASK SCRIPT

A task script was available to guide each participant through the requirements of the activity. The participant could choose from a set of options that would affect either the measurement calculation or the analysis of the resultant data. The order of the script was as follows:

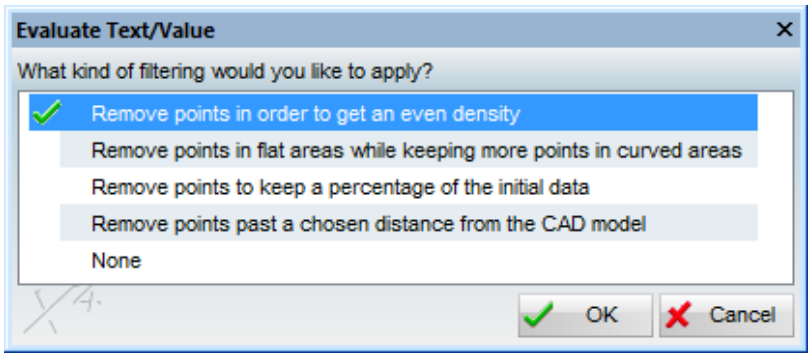
1. Demographic details
2. Task requirements and execution of measurements and/or analysis
3. Evaluation of the task

A video clip of the script is available to CMS members at www.CMSC.org.

MEASUREMENT TASK SCRIPT DETAILS

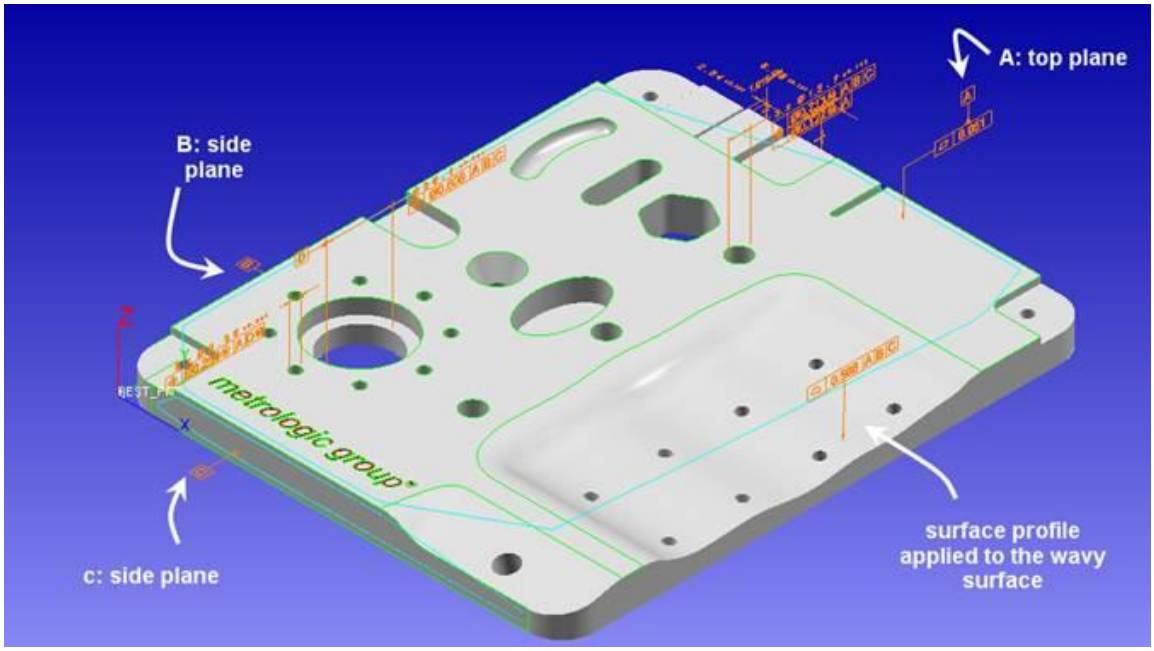
Filtering

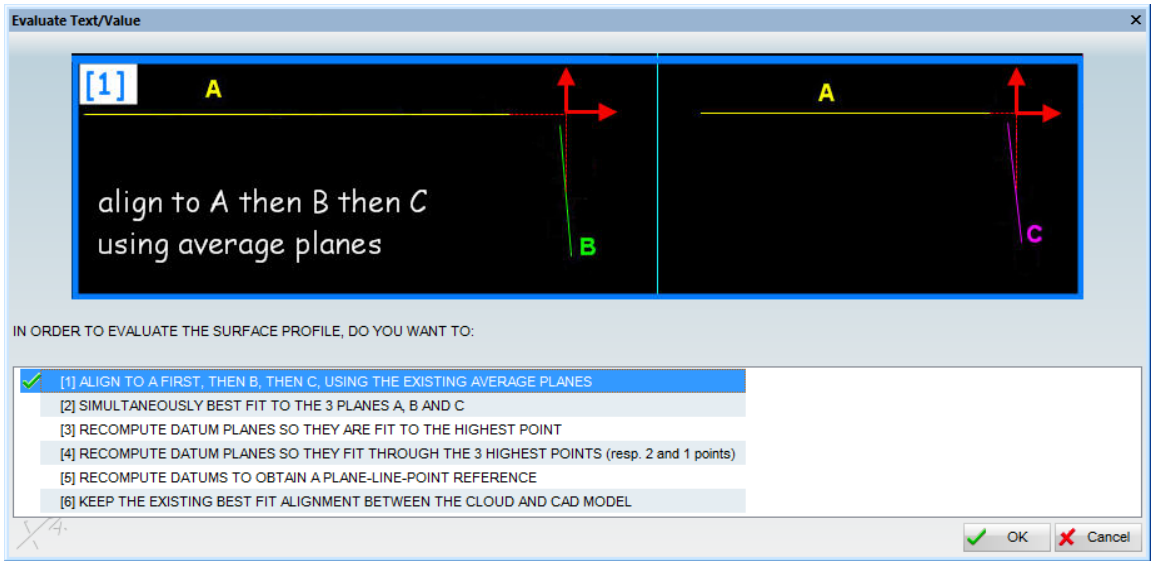
Objective: To evaluate the filtering choices to clean the point cloud obtained prior to the alignment process and analysis. For each selection from the user, he or she would then be prompted to enter a parameter related to the type of filtering selected.

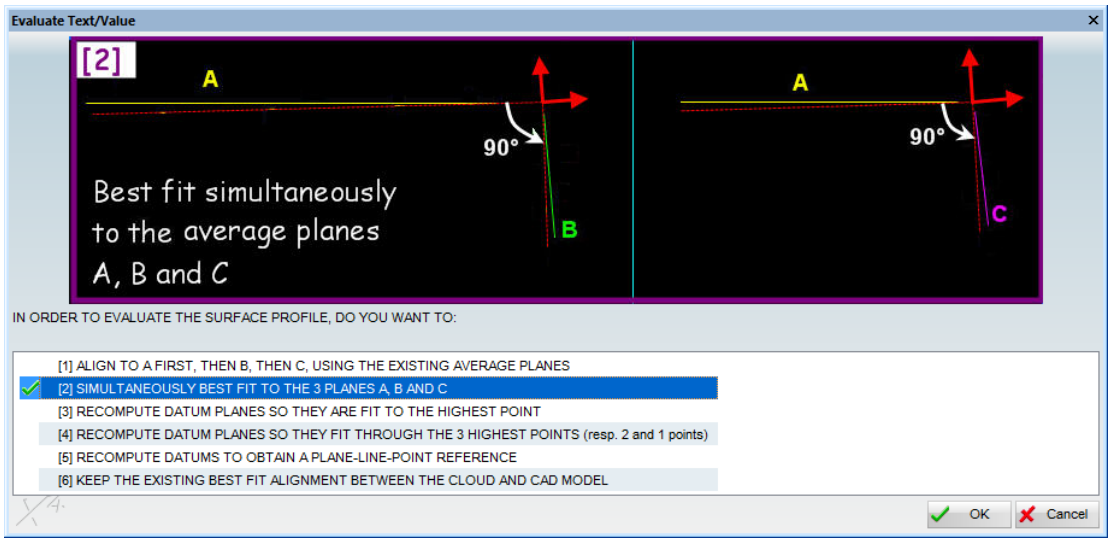


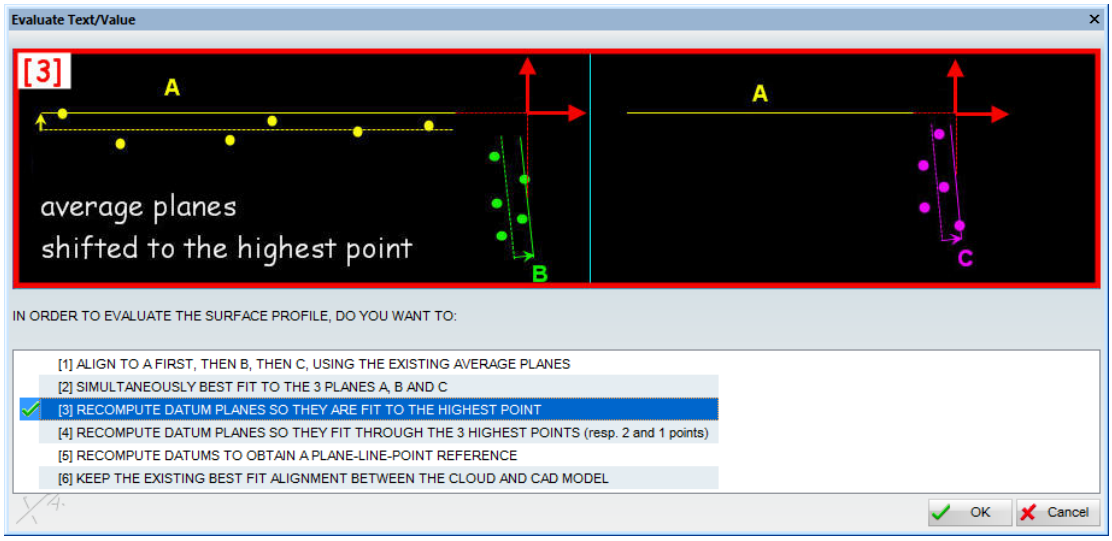
Alignment Method

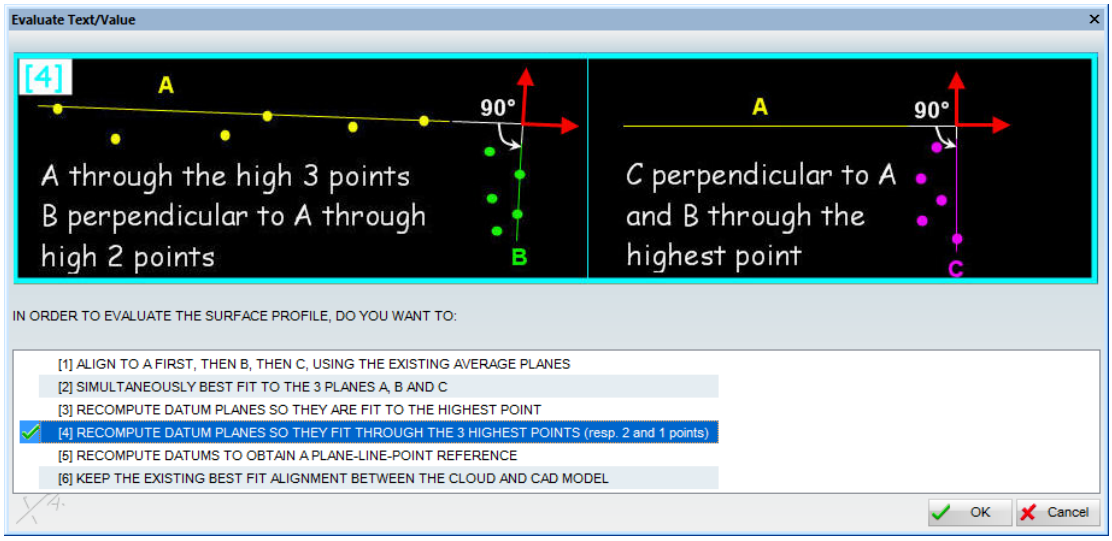
Objective: To evaluate a surface profile to A|B|C and then ask the user to make the appropriate choices to create the alignment to Datum's ABC. The participant was prompted to choose from 6 different computation methods for the datums, each illustrated by a picture:

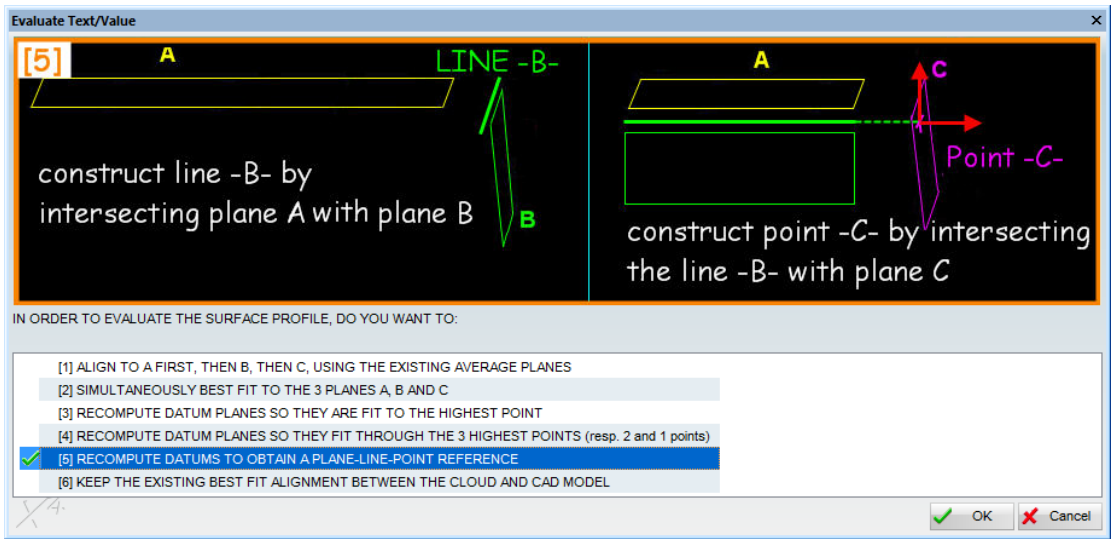


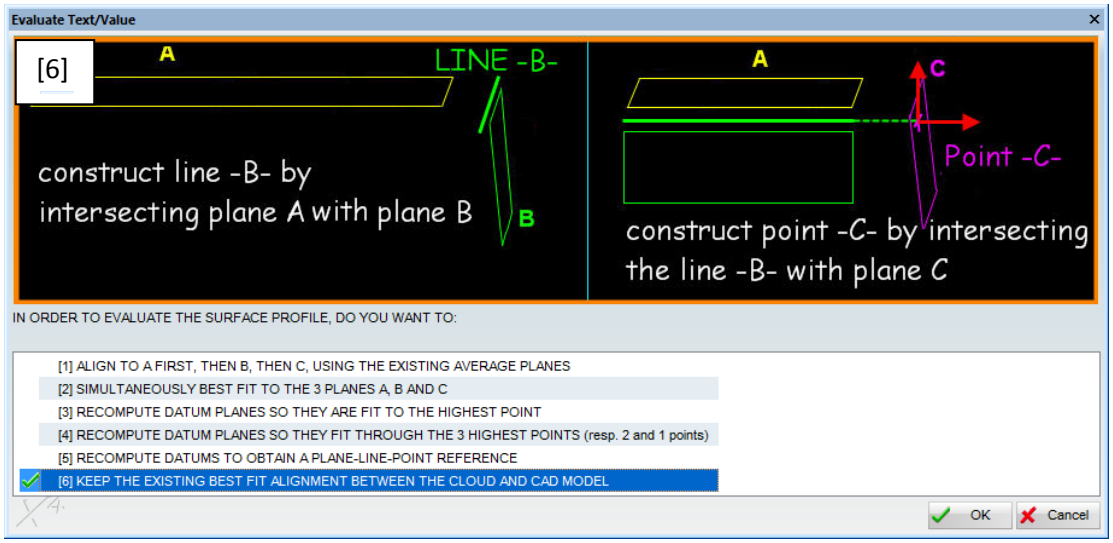



Evaluate Text/Value
[2]
A
90°
B
Best fit simultaneously
to the average planes
A, B and C
A
90°
C
IN ORDER TO EVALUATE THE SURFACE PROFILE, DO YOU WANT TO:
[1] ALIGN TO A FIRST, THEN B, THEN C, USING THE EXISTING AVERAGE PLANES
[2] SIMULTANEOUSLY BEST FIT TO THE 3 PLANES A, B AND C
[3] RECOMPUTE DATUM PLANES SO THEY ARE FIT TO THE HIGHEST POINT
[4] RECOMPUTE DATUM PLANES SO THEY FIT THROUGH THE 3 HIGHEST POINTS (resp. 2 and 1 points)
[5] RECOMPUTE DATUMS TO OBTAIN A PLANE-LINE-POINT REFERENCE
[6] KEEP THE EXISTING BEST FIT ALIGNMENT BETWEEN THE CLOUD AND CAD MODEL
OK
Cancel


Evaluate Text/Value
[3]
A
average planes
shifted to the highest point
B
A
C
IN ORDER TO EVALUATE THE SURFACE PROFILE, DO YOU WANT TO:
[1] ALIGN TO A FIRST, THEN B, THEN C, USING THE EXISTING AVERAGE PLANES
[2] SIMULTANEOUSLY BEST FIT TO THE 3 PLANES A, B AND C
[3] RECOMPUTE DATUM PLANES SO THEY ARE FIT TO THE HIGHEST POINT
[4] RECOMPUTE DATUM PLANES SO THEY FIT THROUGH THE 3 HIGHEST POINTS (resp. 2 and 1 points)
[5] RECOMPUTE DATUMS TO OBTAIN A PLANE-LINE-POINT REFERENCE
[6] KEEP THE EXISTING BEST FIT ALIGNMENT BETWEEN THE CLOUD AND CAD MODEL
OK
Cancel


Evaluate Text/Value
[4]
A
90°
A through the high 3 points
B perpendicular to A through
high 2 points
B
A
90°
C perpendicular to A
and B through the
highest point
C
IN ORDER TO EVALUATE THE SURFACE PROFILE, DO YOU WANT TO:
[1] ALIGN TO A FIRST, THEN B, THEN C, USING THE EXISTING AVERAGE PLANES
[2] SIMULTANEOUSLY BEST FIT TO THE 3 PLANES A, B AND C
[3] RECOMPUTE DATUM PLANES SO THEY ARE FIT TO THE HIGHEST POINT
[4] RECOMPUTE DATUM PLANES SO THEY FIT THROUGH THE 3 HIGHEST POINTS (resp. 2 and 1 points)
[5] RECOMPUTE DATUMS TO OBTAIN A PLANE-LINE-POINT REFERENCE
[6] KEEP THE EXISTING BEST FIT ALIGNMENT BETWEEN THE CLOUD AND CAD MODEL
OK
Cancel


Evaluate Text/Value
[5]
A
LINE -B-
construct line -B- by
intersecting plane A with plane B
B
A
C
Point -C-
construct point -C- by intersecting
the line -B- with plane C
IN ORDER TO EVALUATE THE SURFACE PROFILE, DO YOU WANT TO:
[1] ALIGN TO A FIRST, THEN B, THEN C, USING THE EXISTING AVERAGE PLANES
[2] SIMULTANEOUSLY BEST FIT TO THE 3 PLANES A, B AND C
[3] RECOMPUTE DATUM PLANES SO THEY ARE FIT TO THE HIGHEST POINT
[4] RECOMPUTE DATUM PLANES SO THEY FIT THROUGH THE 3 HIGHEST POINTS (resp. 2 and 1 points)
[5] RECOMPUTE DATUMS TO OBTAIN A PLANE-LINE-POINT REFERENCE
[6] KEEP THE EXISTING BEST FIT ALIGNMENT BETWEEN THE CLOUD AND CAD MODEL
OK
Cancel


Evaluate Text/Value
[6]
A
LINE -B-
construct line -B- by
intersecting plane A with plane B
B
A
C
Point -C-
construct point -C- by intersecting
the line -B- with plane C
IN ORDER TO EVALUATE THE SURFACE PROFILE, DO YOU WANT TO:
[1] ALIGN TO A FIRST, THEN B, THEN C, USING THE EXISTING AVERAGE PLANES
[2] SIMULTANEOUSLY BEST FIT TO THE 3 PLANES A, B AND C
[3] RECOMPUTE DATUM PLANES SO THEY ARE FIT TO THE HIGHEST POINT
[4] RECOMPUTE DATUM PLANES SO THEY FIT THROUGH THE 3 HIGHEST POINTS (resp. 2 and 1 points)
[5] RECOMPUTE DATUMS TO OBTAIN A PLANE-LINE-POINT REFERENCE
[6] KEEP THE EXISTING BEST FIT ALIGNMENT BETWEEN THE CLOUD AND CAD MODEL
OK
Cancel

For each task, the proctor was required to observe specific actions and responses by the participant and note them on the following observation sheets:

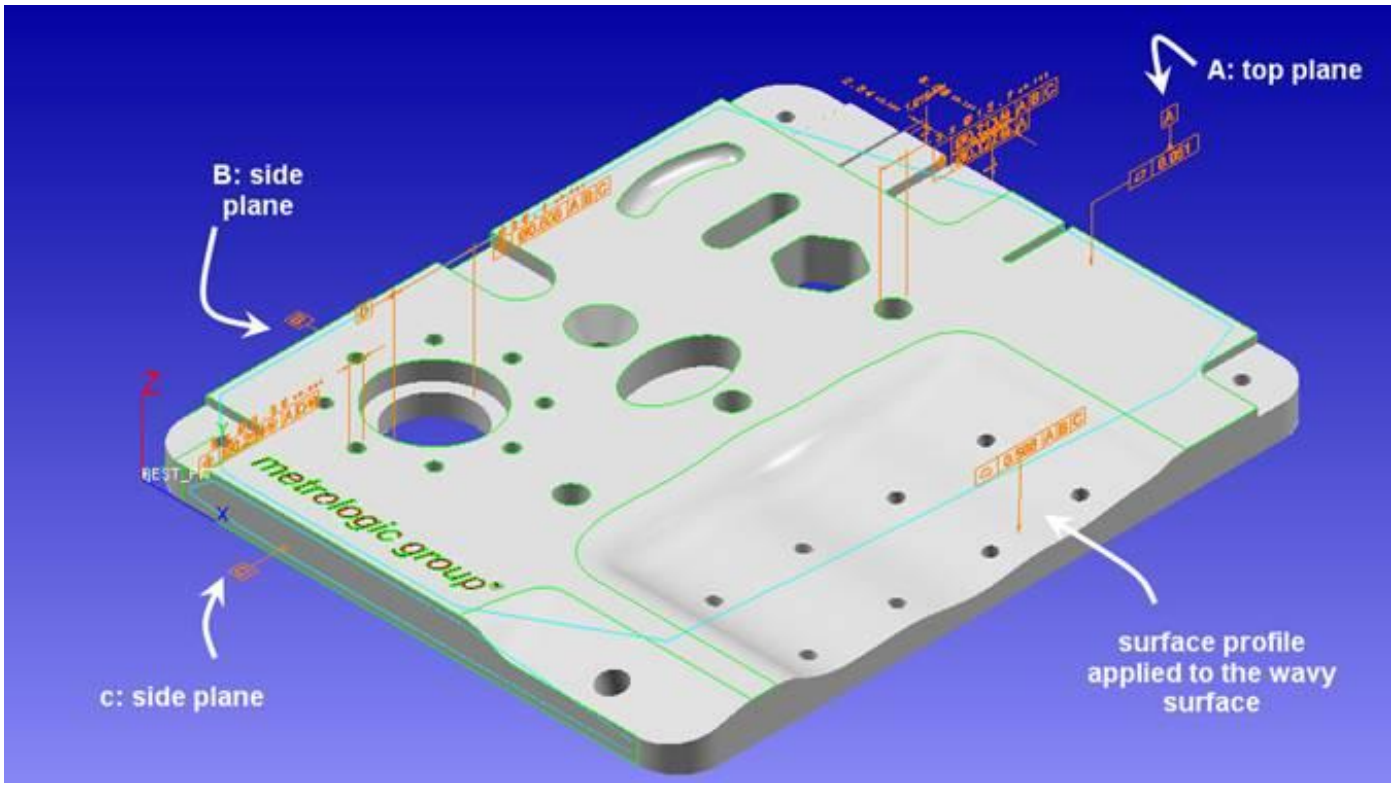
Observation Sheet
Participant Number…… Practical
Identify the participant category

1. Beginner to Measurement
2. Beginner to Non-Contact Scanning with a PCMM
3. Some experience of Non-Contact Scanning with a PCMM
4. Experienced in Non-Contact Scanning with a PCMM

Introduction:

At the beginning of the measurement task, the proctor explained to the participant that the intent is to measure the part with the provided measuring device and scanner. The participant was required to scan an artifact, complete demographics questions, follow a scripted procedure to evaluate the scanned data, and at the end of the procedure, complete a series of evaluation questions. Upon completion, the participant was invited to sign up for the second task, if they had not already done so.

Practical Stations: the objective was to measure the part and analyze the data against the specified tolerances.



The participant was told to take usual precautions as if they were to inspect a part for a buy off.

Notes for the Proctor

- If the participant was a beginner to measurement and/or portable measurement systems, the proctor asked the participant if they have any questions about the setup before getting started (first opportunity to check on environmental conditions, equipment, probes, stability, etc).

- If the participant has some experience, then they should be able to identify the behaviors required before, during and after the measurement. Monitor their behavior and answer the appropriate questions in the supplied document based on your observations.

ENVIRONMENTAL CHECKS	
User inquires about **temperature**	a) Yes b) No
User inquires about other environmental issues	a) Yes b) No
WORK AREA CHECKS	
Regarding the part **Stability** and **Fixturing**, did the participant:	a) Simply ask about it b) Make sure the part was stable then (re)measured the part c) Ignore that aspect d) Correct the stability half way through the task without re-measuring features measured prior?
EQUIPMENT CONSIDERATIONS	
Did the participant ask about: **Device uncertainty/precision**?	a) Yes b) No
Did the participant ask about: **Device calibration**?	a) Yes b) No
Did the participant ask about: **Device stability**?	a) Yes b) No
Did the participant ask about: **Optical scanner calibration/qualification**?	a) Yes b) No
Did the participant inquire about the position of the part relative to the device (to check **reachability**)?	a) Yes b) No
Did the participant have questions about the **tolerances** displayed on the screen?	a) Yes b) No
Does the participant inquire about how to position/hold the scanner relative to the surface probed?	a) Yes b) No

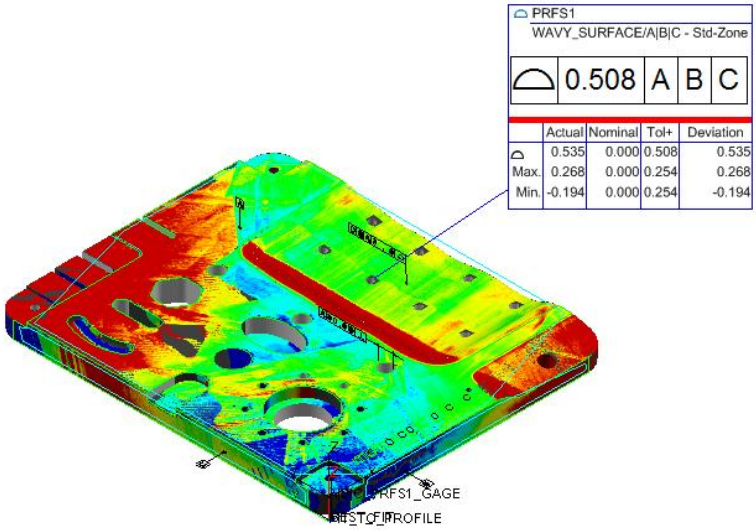
Does the participant ask about how close they should be from the intended point?	a) Yes b) No
Did the participant ask about the **point density** settings before the measurement began?	a) Yes b) No
Did the participant try to collect points all over the surface?	a) Yes b) No
Did the participant ask about the speed of data collection?	a) Yes b) No

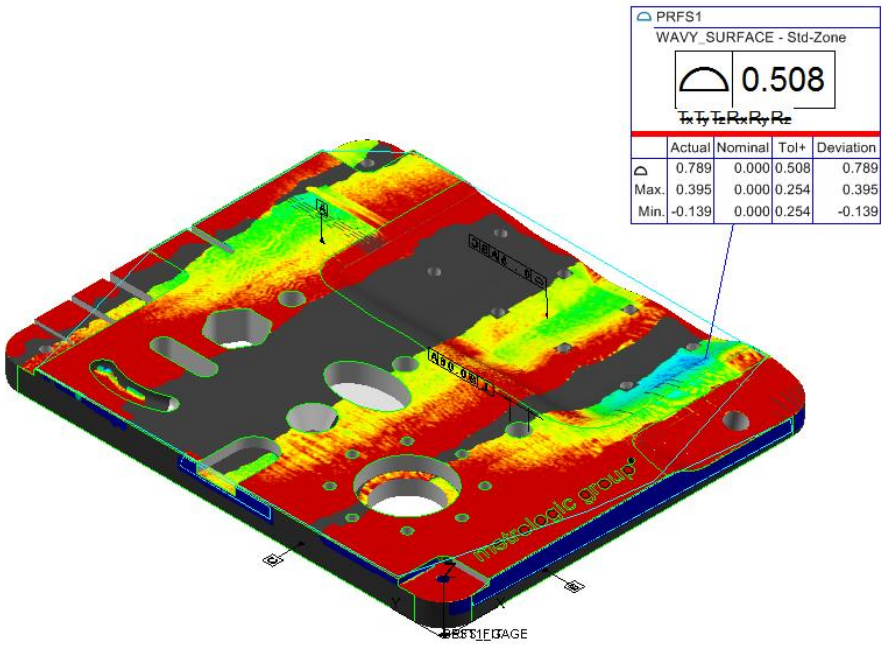
SCRIPT	
Did the participant ask about **filtering** requirements?	a) Yes b) No
Did the participant ask about **point cloud spacing** requirements?	a) Yes b) No
Did the participant inquire about the **datum features**?	a) Yes b) No
Did the participant inquire about the **alignment method**?	a) Yes b) No
Did the participant ask about **what features** needs to be measured?	a) Yes b) No
Did the participant ask about the **sequence of the measurements**?	a) Yes b) No

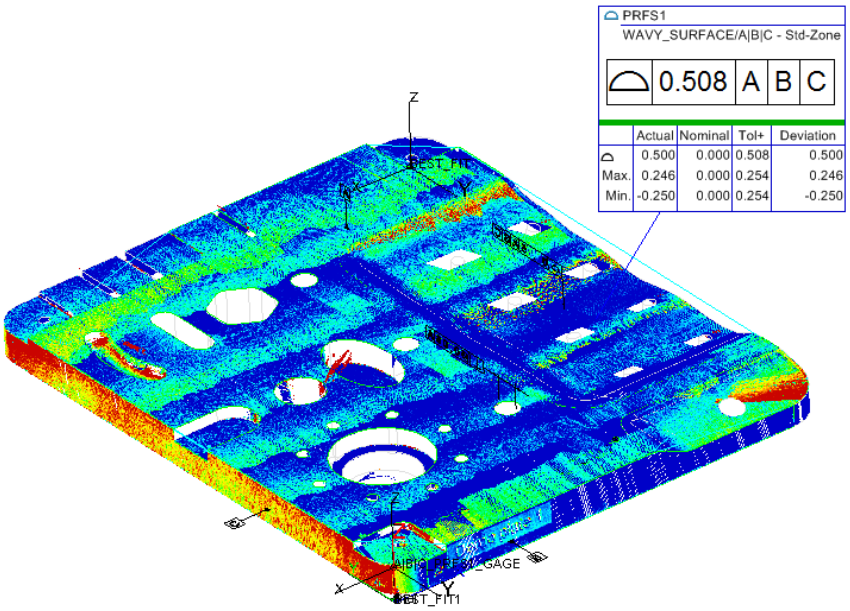
AFTER	
Did the participants inquire about the **results**?	a) Yes b) No
Did the participant **repeat** any doubtful **measurements** or ask for the measurement to be repeated?	a) Yes b) No
Did the participant identify the reason for repeating measurement (such as: form error, measurement error, wrong feature measured, etc)?	a) Yes b) No
Other observations (if any)	

TASK SCRIPT RESULTS FROM THE MEASUREMENT TASK

The following results give an overview of the range of the final output of the profile of a surface tolerance callout. Results varied up to 2,373 mm.



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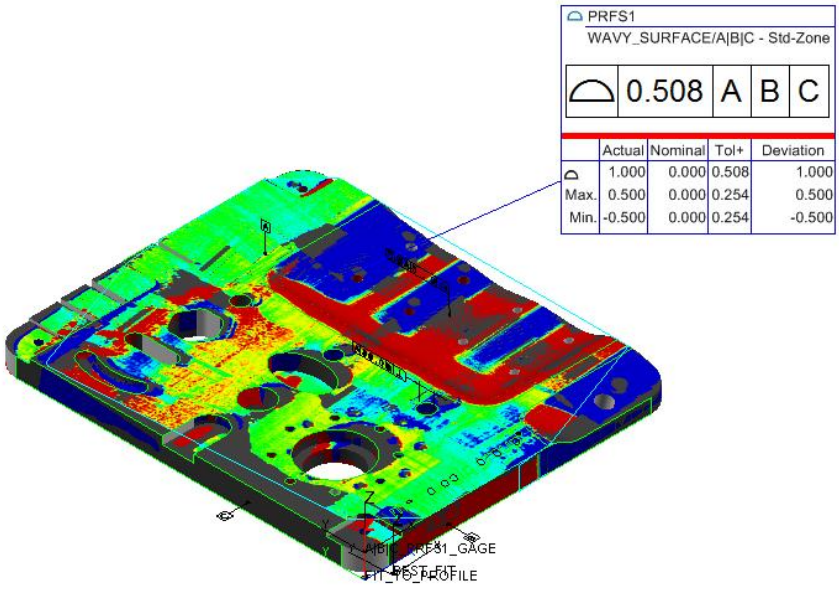
WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
Max. 0.246 0.000 0.254 0.246
Min. -0.250 0.000 0.254 -0.250
Z
BEST_FIT
A|B|C_REF_GAGE
BEST_FIT1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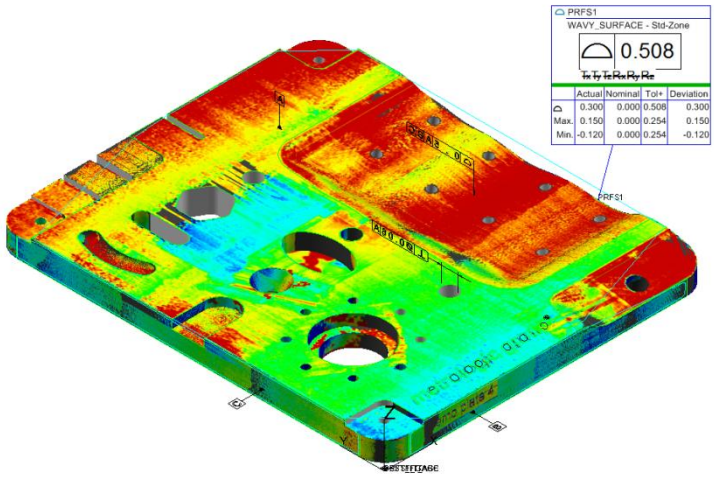
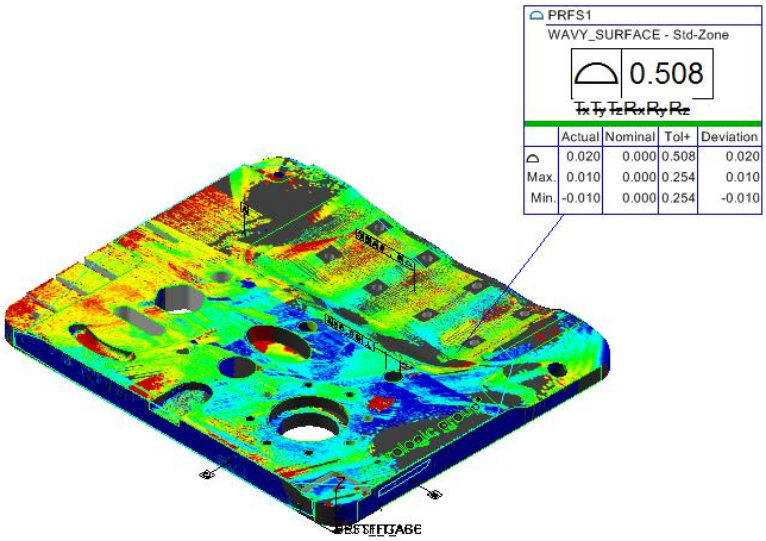
0.508 A B C
Actual Nominal Tol+ Deviation
Max. 0.500 0.000 0.254 0.500
Min. -0.500 0.000 0.254 -0.500
A|B|C_REF1_GAGE
BEST_FIT
FIT_TO_PROFILE


PRFS1
WAVY_SURFACE - Std-Zone
0.508
Tx Ty Tz Rx Ry Rz
Actual Nominal Tol+ Deviation
0.300 0.000 0.508 0.300
Max. 0.150 0.000 0.254 0.150
Min. -0.120 0.000 0.254 -0.120
PRFS1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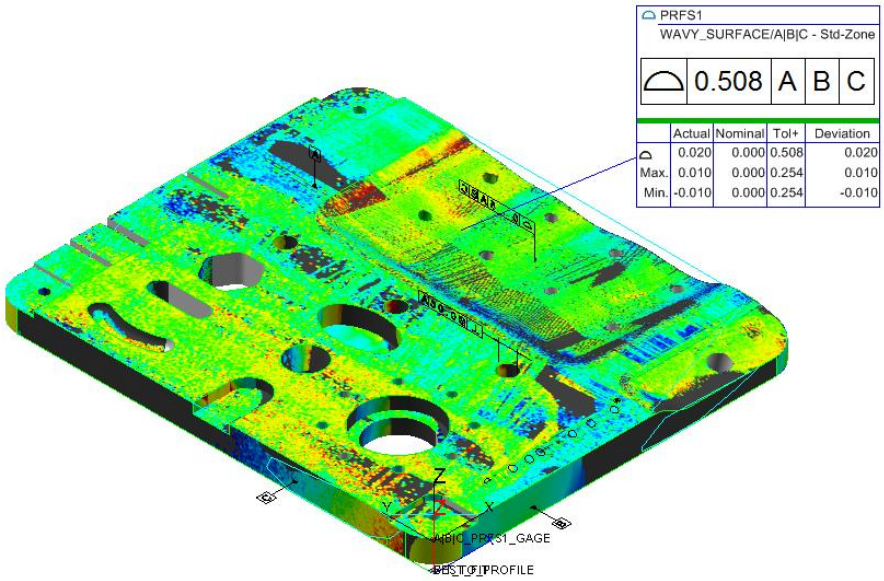
0.508
Tx Ty Tz Rx Ry Rz
Actual Nominal Tol+ Deviation
0.020 0.000 0.508 0.020
Max. 0.010 0.000 0.254 0.010
Min. -0.010 0.000 0.254 -0.010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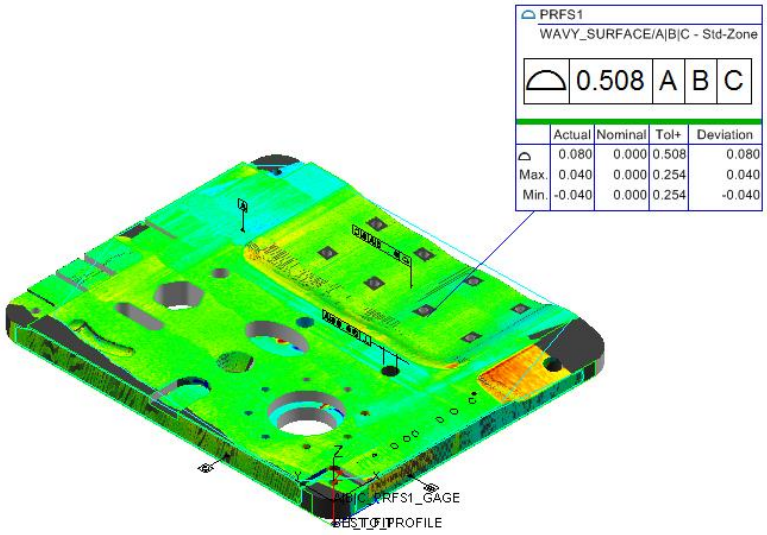
0.508 A B C
Actual Nominal Tol+ Deviation
0.020 0.000 0.508 0.020
Max. 0.010 0.000 0.254 0.010
Min. -0.010 0.000 0.254 -0.010
MBIC_PRFS1_GAGE
BEST_FIT_PROFILE


PRFS1
WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
0.080 0.000 0.508 0.080
Max. 0.040 0.000 0.254 0.040
Min. -0.040 0.000 0.254 -0.040
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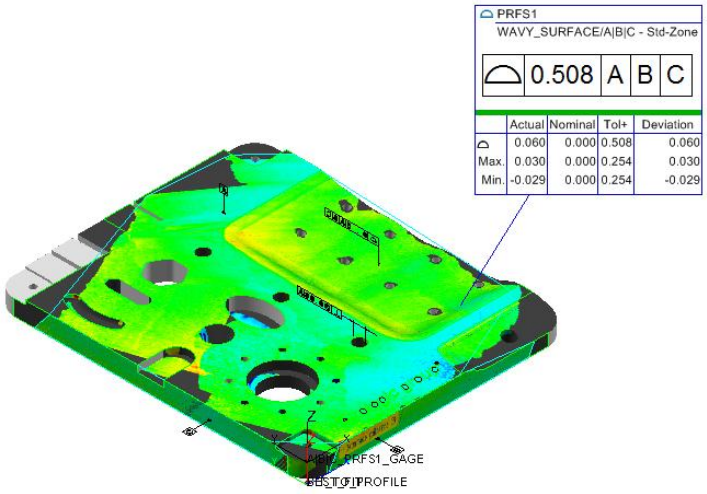
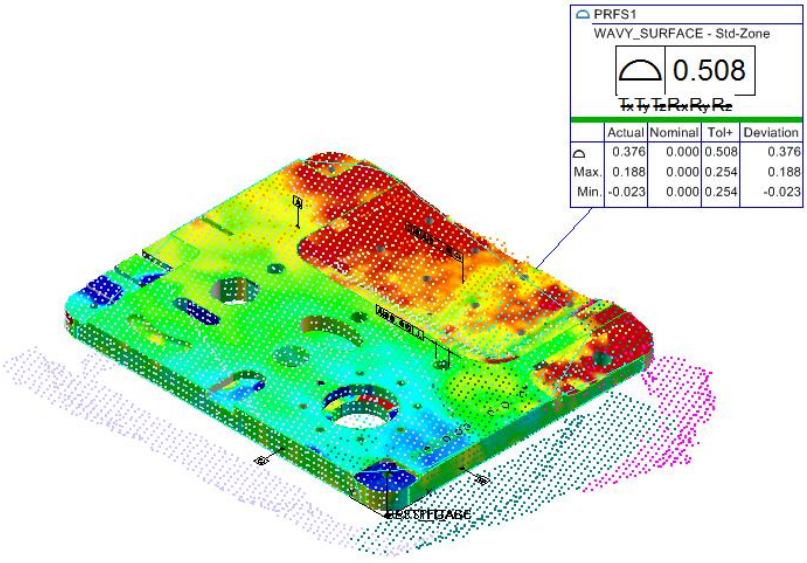
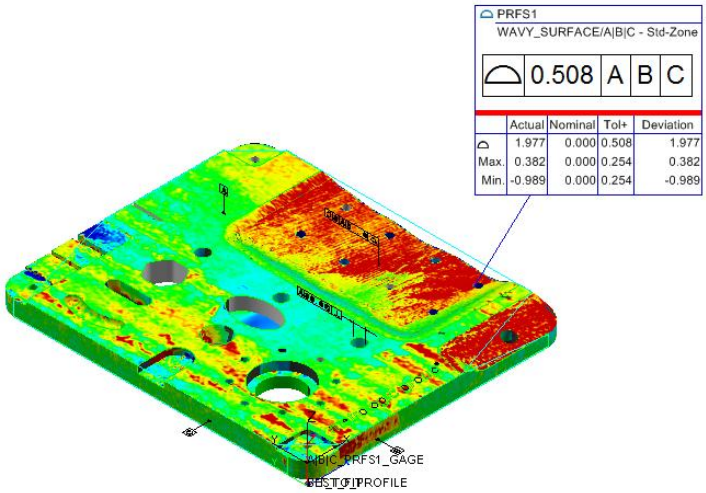

PRFS1
WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
Δ 0.060 0.000 0.508 0.060
Max. 0.030 0.000 0.254 0.030
Min. -0.029 0.000 0.254 -0.029
PRFS1_GAGE
BEST FIT PROFILE


PRFS1
WAVY_SURFACE - Std-Zone
0.508
Tx Ty Tz Rx Ry Rz
Actual Nominal Tol+ Deviation
Δ 0.376 0.000 0.508 0.376
Max. 0.188 0.000 0.254 0.188
Min. -0.023 0.000 0.254 -0.023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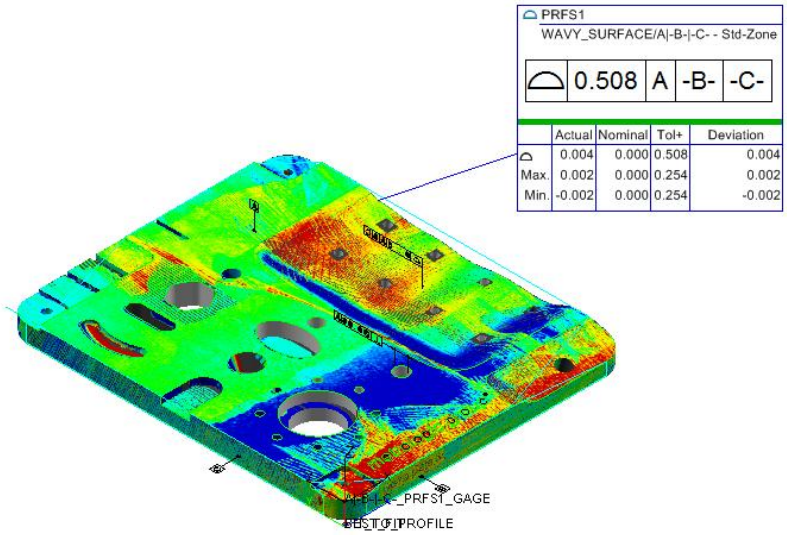
0.508 A B C
Actual Nominal Tol+ Deviation
1.977 0.000 0.508 1.977
Max. 0.382 0.000 0.254 0.382
Min. -0.989 0.000 0.254 -0.989
MBIC_PRFS1_GAGE
BEST_FIT_PROFILE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WAVY_SURFACE/A|-B-|-C- - Std-Zone
0.508 A -B- -C-
Actual Nominal Tol+ Deviation
0.004 0.000 0.508 0.004
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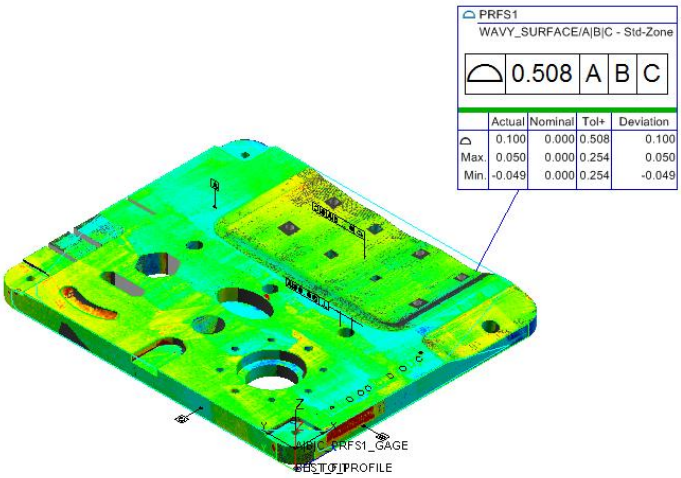
Min. -0.002 0.000 0.254 -0.002
MBIC_PRFS1_GAGE
BEST_FIT_PROFILE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WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
0.100 0.000 0.508 0.100
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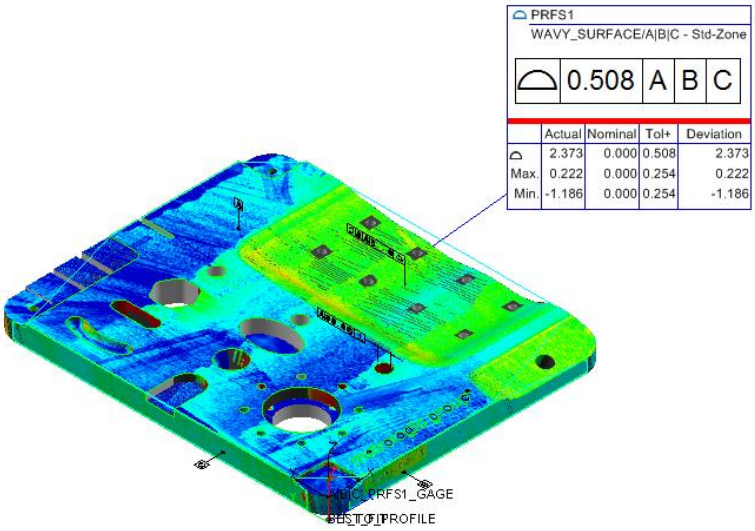
Min. -0.049 0.000 0.254 -0.049
ABC_PRFS1_GAGE
BEST_FIT_PROFILE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Actual Nominal Tol+ Deviation
2.373 0.000 0.508 2.373
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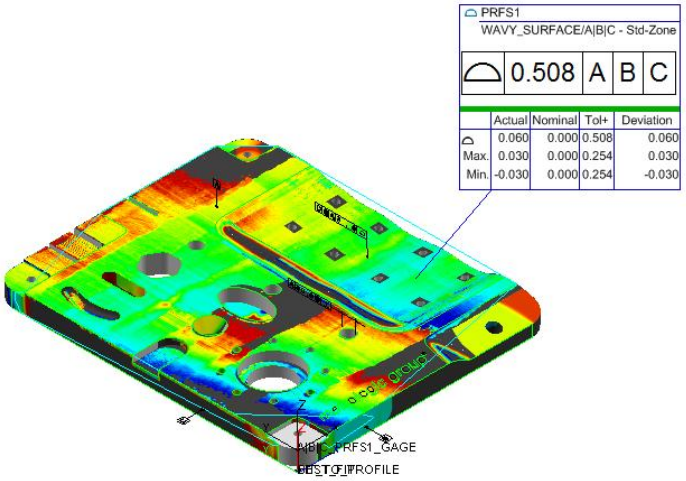
Min. -1.186 0.000 0.254 -1.186
ABC_PRFS1_GAGE
BEST_FIT_PROFILE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WAVY_SURFACE/A|B|C - Std-Zone
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Actual Nominal Tol+ Deviation
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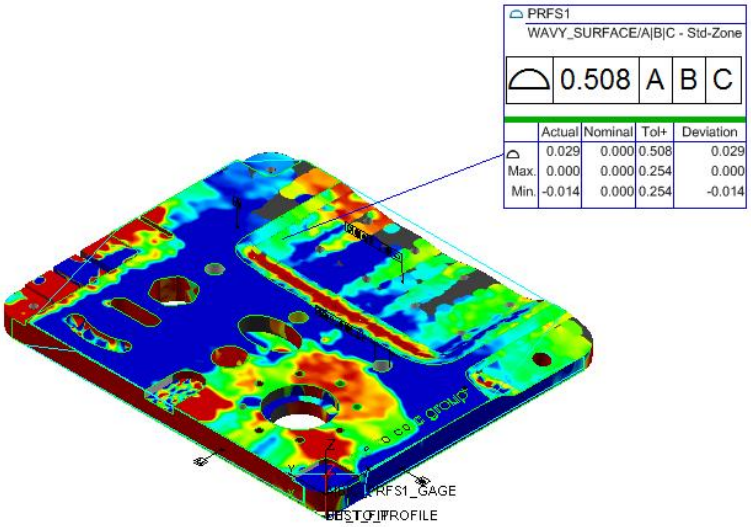
Min. -0.030 0.000 0.254 -0.030
PRFS1_GAGE
BEST_FIT_PROFILE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WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
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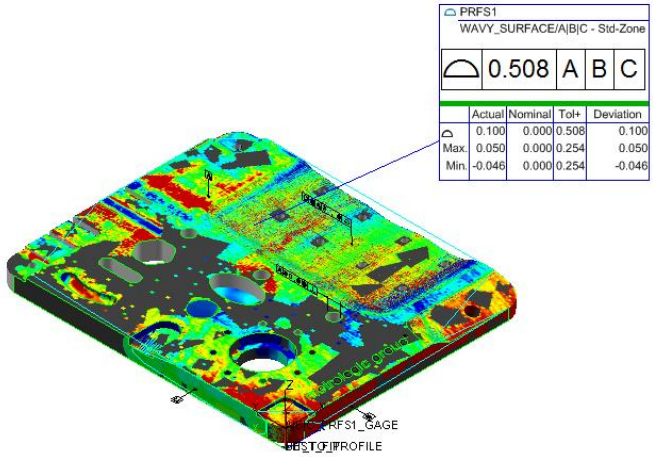
PRFS1_GAGE
BEST_FIT_PROFILE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WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
D 0.100 0.000 0.508 0.100
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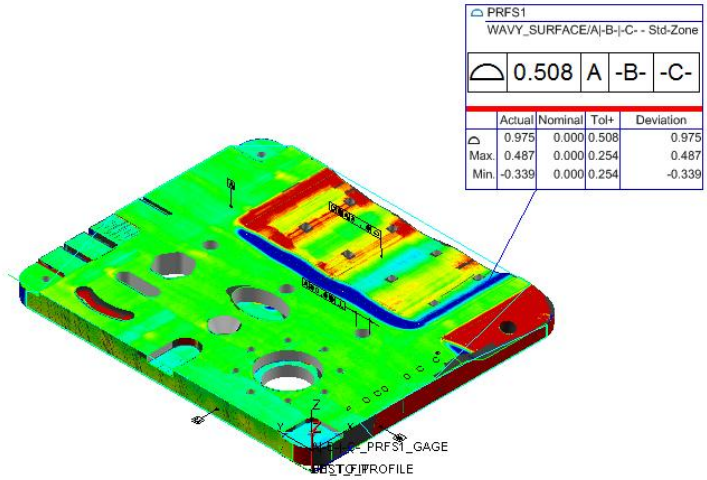
Min. -0.046 0.000 0.254 -0.046
PRFS1_GAGE
BEST_FIT_PROFILE


PRFS1
WAVY_SURFACE/A|-B-|-C- - Std-Zone
0.508 A -B- -C-
Actual Nominal Tol+ Deviation
D 0.975 0.000 0.508 0.975
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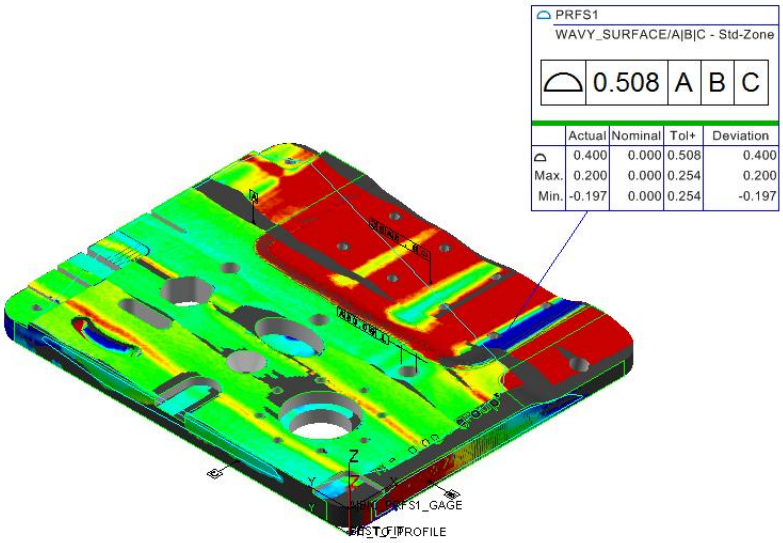
Min. -0.339 0.000 0.254 -0.339
PRFS1_GAGE
BEST_FIT_PROFILE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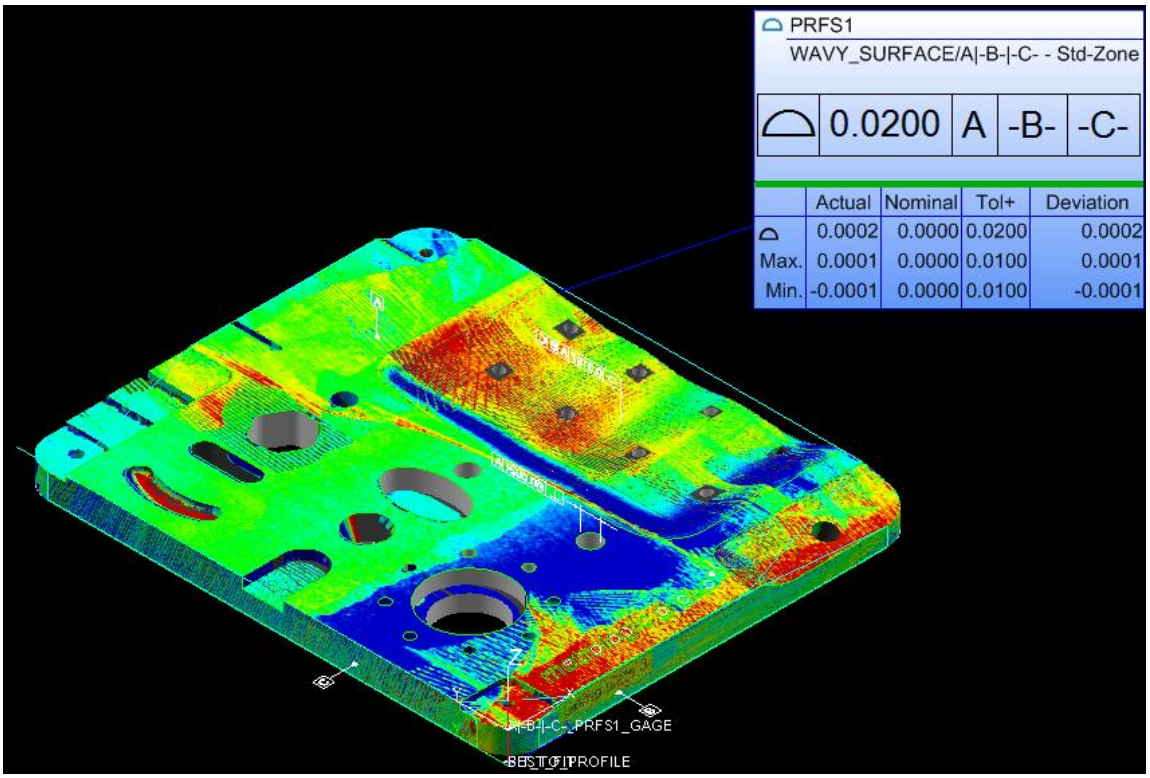
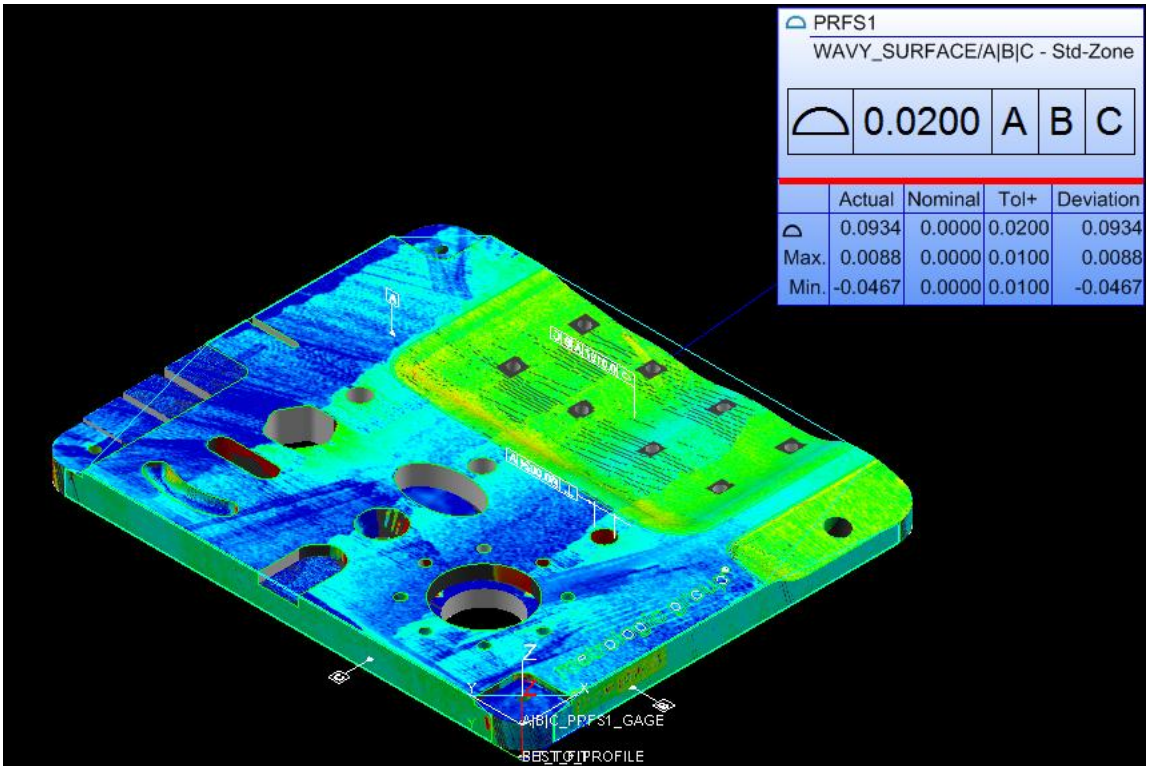
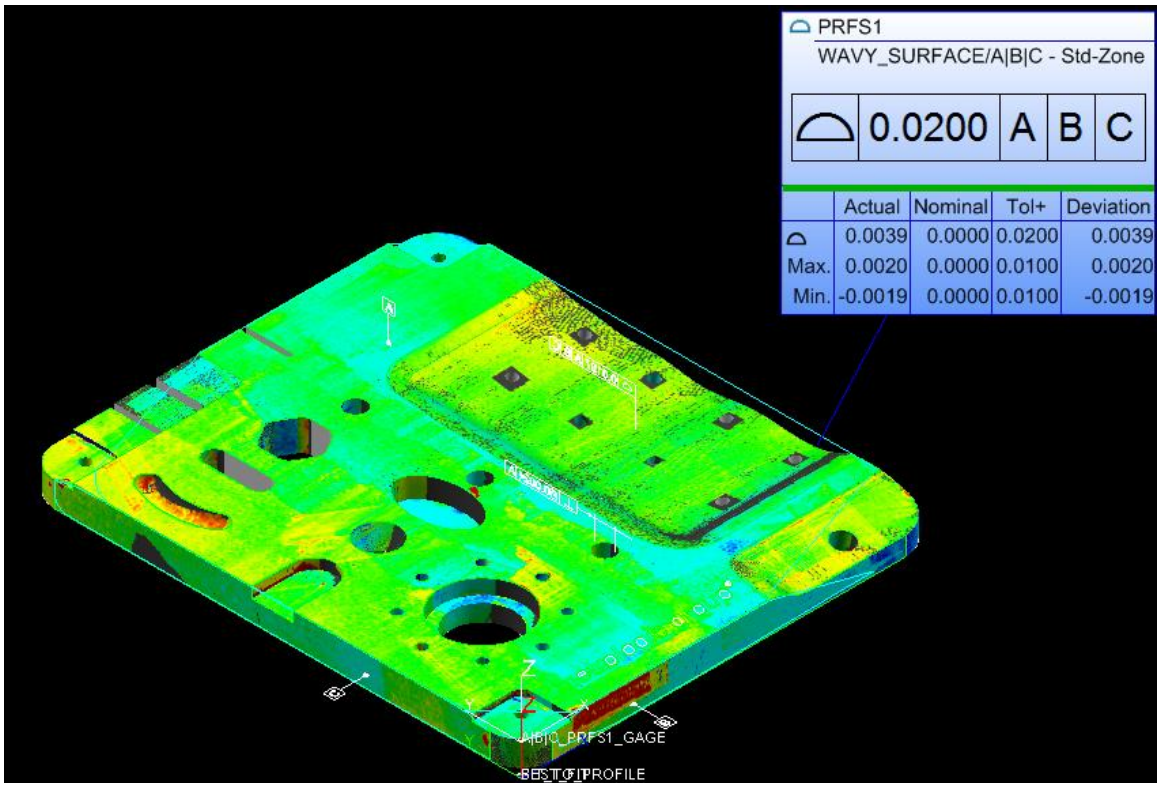
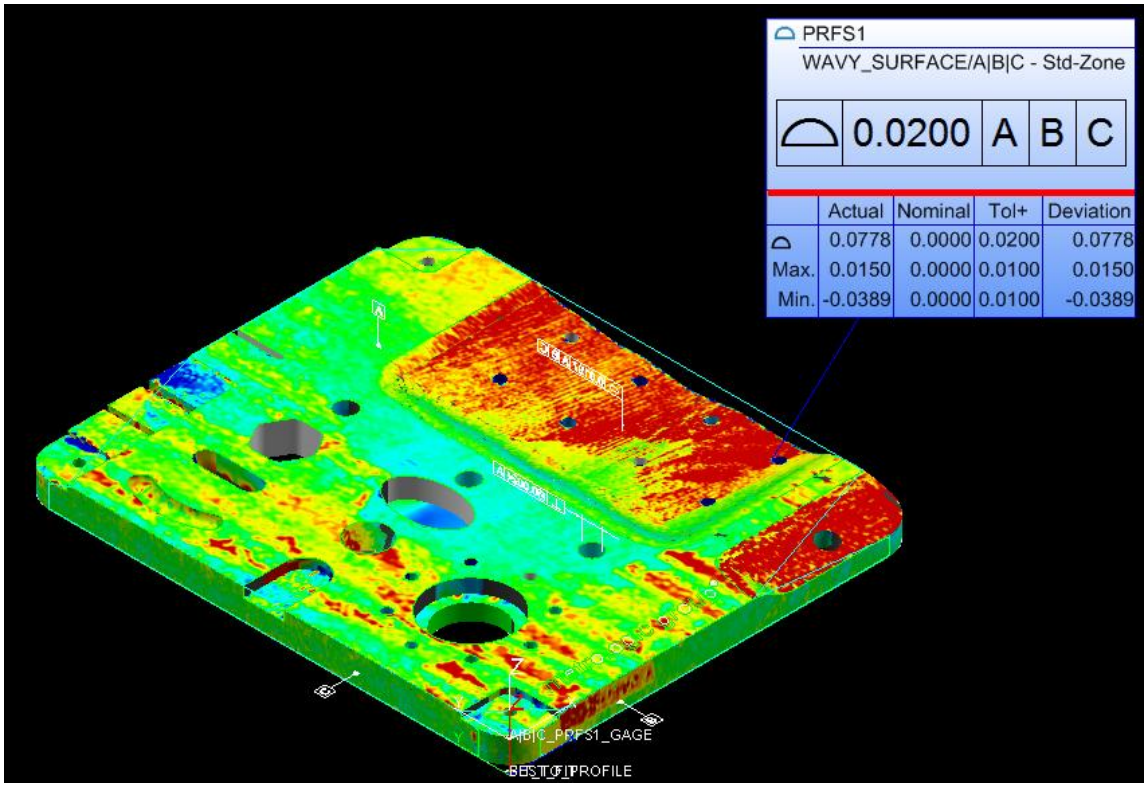
WAVY_SURFACE/A|B|C - Std-Zone
0.508 A B C
Actual Nominal Tol+ Deviation
Max. 0.400 0.000 0.508 0.400
Min. 0.200 0.000 0.254 0.200
-0.197 0.000 0.254 -0.197
PRFS1_GAGE
BEST_FIT_PROFILE

The following graphs show the variation of 6 samples taken on one measurement system.






PRFS1
WAVY_SURFACE/A|B|C - Std-Zone
0.0200 A B C
Actual Nominal Tol+ Deviation
0.0039 0.0000 0.0200 0.0039
Max. 0.0020 0.0000 0.0100 0.0020
Min. -0.0019 0.0000 0.0100 -0.0019
A|B|C_PRFS1_GAGE
BEST FIT PROFILE


PRFS1
WAVY_SURFACE/A|B|C - Std-Zone
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Actual Nominal Tol+ Deviation
0.0778 0.0000 0.0200 0.0778
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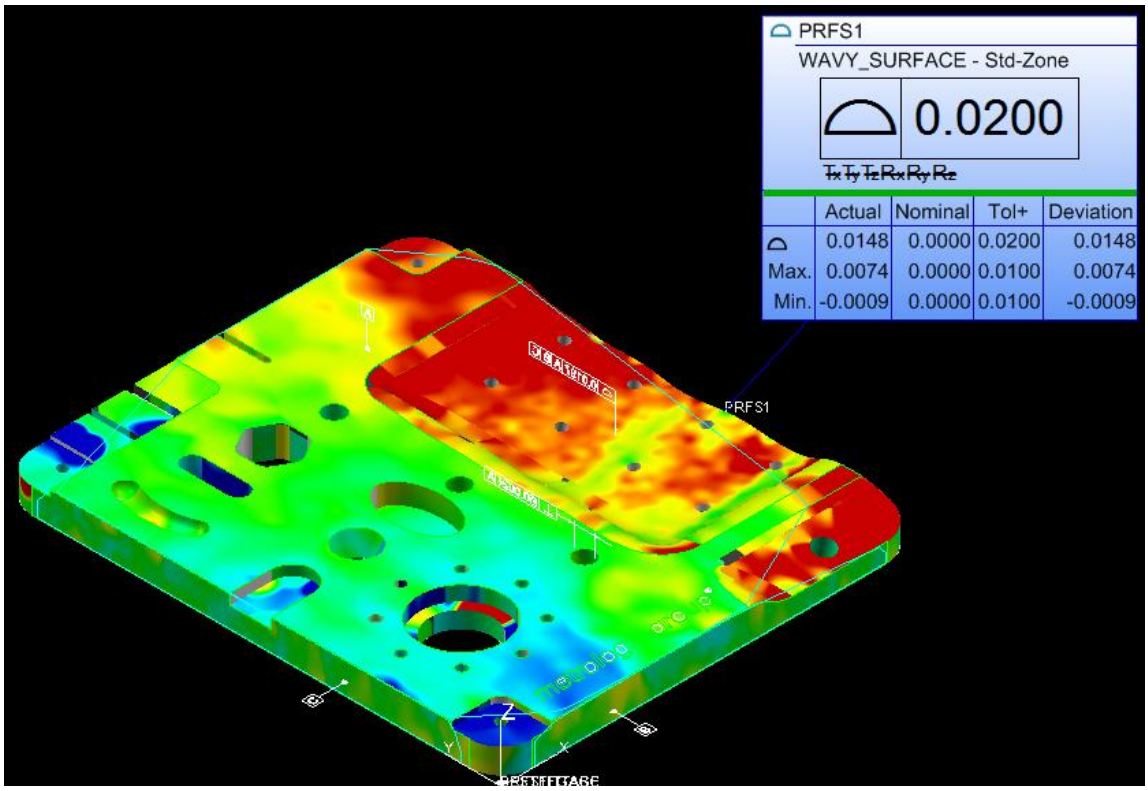
A|B|C_PRFS1_GAGE
BEST FIT PROFILE


PRFS1
WAVY_SURFACE - Std-Zone
0.0200
Tx Ty Tz Rx Ry Rz
Actual Nominal Tol+ Deviation
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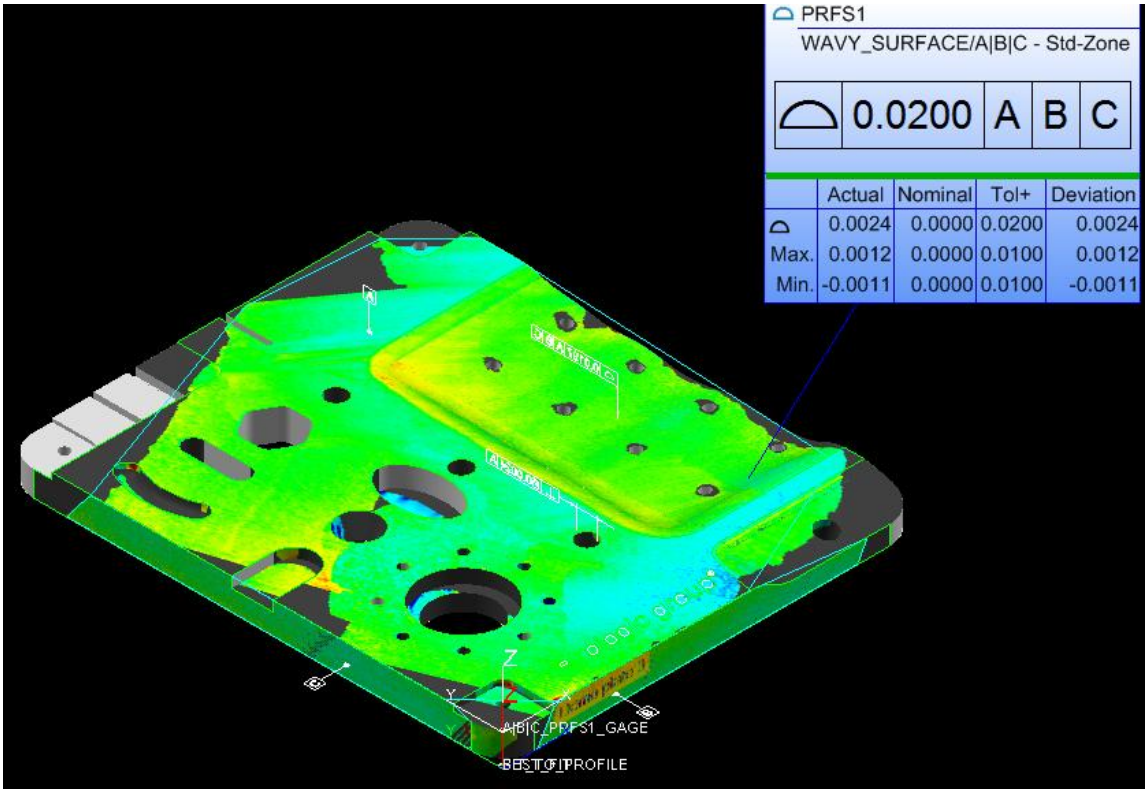
PRFS1


PRFS1
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Actual Nominal Tol+ Deviation
0.0024 0.0000 0.0200 0.0024
Max. 0.0012 0.0000 0.0100 0.0012
Min. -0.0011 0.0000 0.0100 -0.0011
A|B|C_PRFS1_GAGE
BEST FIT PROFILE

DATA ANALYSIS TASK SCRIPT

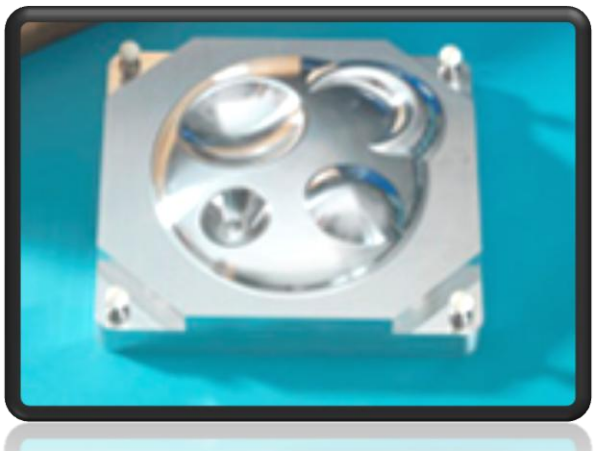
A task script was available to guide each participant through the requirements of the activity. The participant could choose from a set of options that would affect either the measurement calculation or the analysis of the resultant data. The order of the script was as follows:

1. Demographic details
2. Task requirements and execution of measurements and/or analysis
3. Evaluation of the task

A video clip of the script is available to CMS members at www.CMSC.org.

Video clip of the script is available to members on www.cmsc.org

For each task the proctor was required to observe specific actions and responses by the participant and note them on the following observation sheets.



Observation sheets
Participant Number…… Analysis
Identify the participant category

1. Beginner to Data Analysis
2. Some experience of Data Analysis
3. Experienced in Data Analysis

Introduction:

At the beginning of the measurement task, the proctor explained to the participant that the intent is to analyze the part with the data provided. The participant was required to complete demographics questions, follow a scripted procedure choosing their preferred options, and then complete evaluations questions. Upon completion, the participant was invited to sign up for the second task, if they had not already done so.

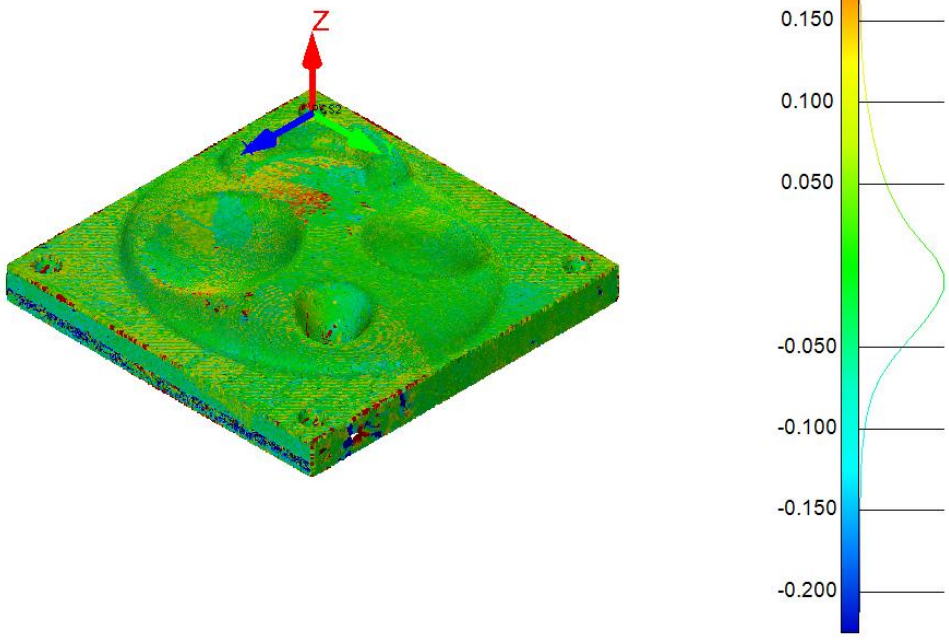
Analysis Stations: the objective was to obtain the dimensions requested, generate a mesh, and compare the overall profile to a second set of data.

The participant was told to take the usual precautions as if they were to inspect a part for a buy off.

Notes for the Proctor

- If the participant was a beginner to measurement and the analysis of data, the proctor asked the participant if they have any questions about the process before getting started.
- Monitor behavior and answer the appropriate questions in the document provided based on their observations.

Observations	
Question	**Available Answers**
Did the participant inquire about the requirements?	a) Yes b) No
Did the participant have questions about the **Filtering requirements?**	a) Yes b) No
Did the participant ask about **point cloud spacing** requirements?	a) Yes b) No
Did the participant trap **enough** of the feature to get a valid result?	a) Yes b) No
Did the participant trap **too much** of the feature to get a valid result?	a) Yes b) No
Did the participant inquire about the **alignment method**?	a) Yes b) No
Did the participant enquire about the **tolerancing** requirements?	a) Yes b) No
Did the participants inquire about the **result** of the data that was analyzed??	a) Yes b) No
Did the participant ask to **repeat** any doubtful **calculations**?	a) Yes b) No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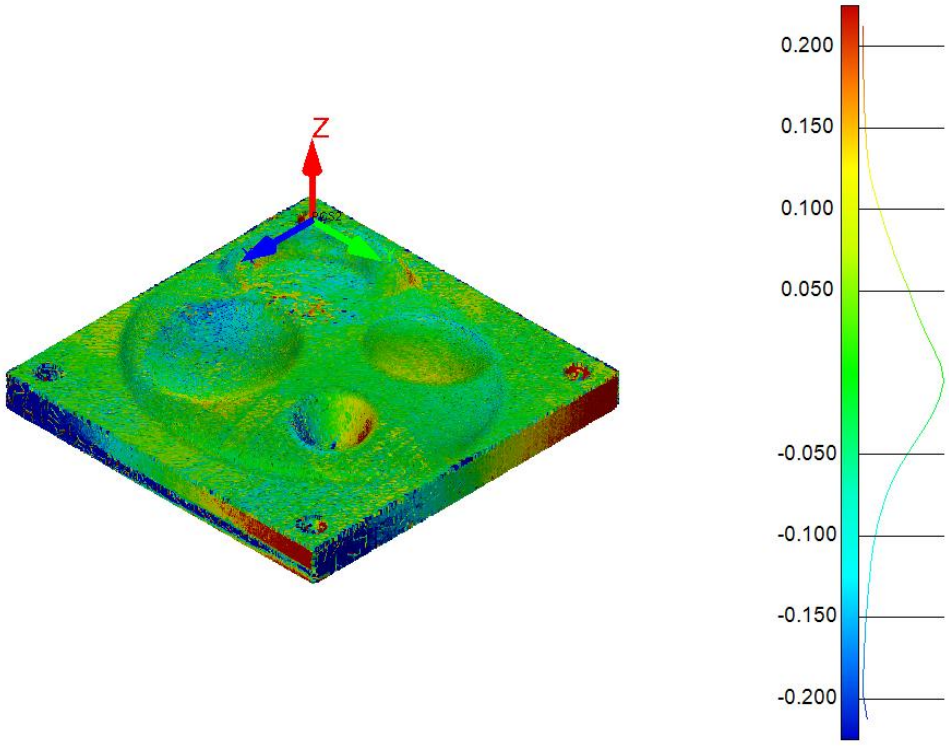
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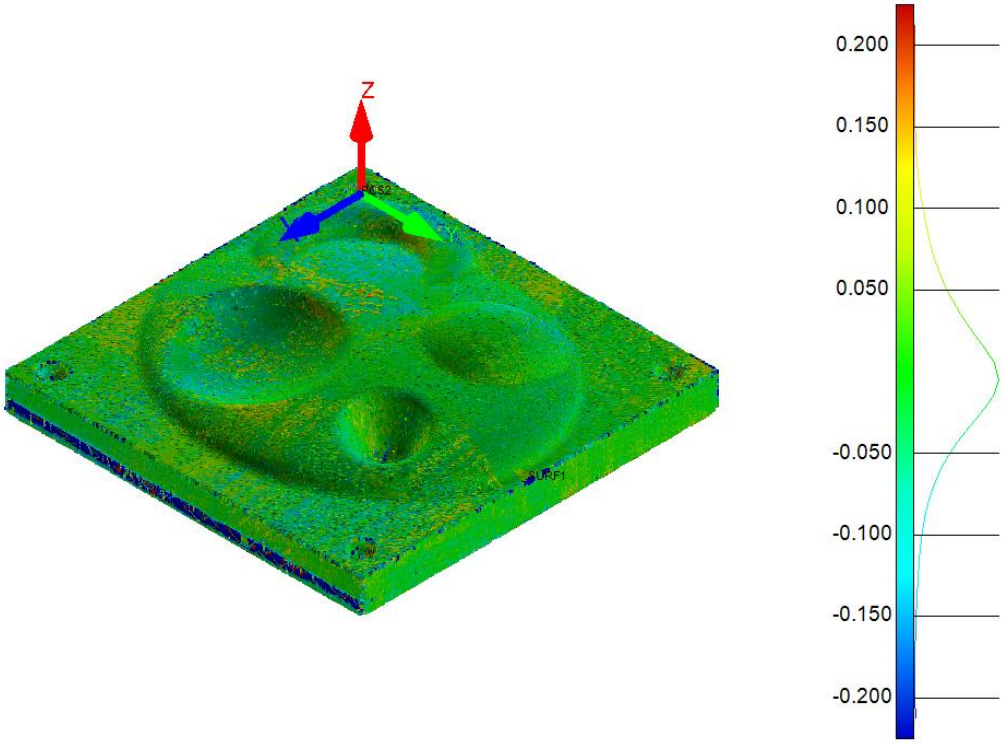
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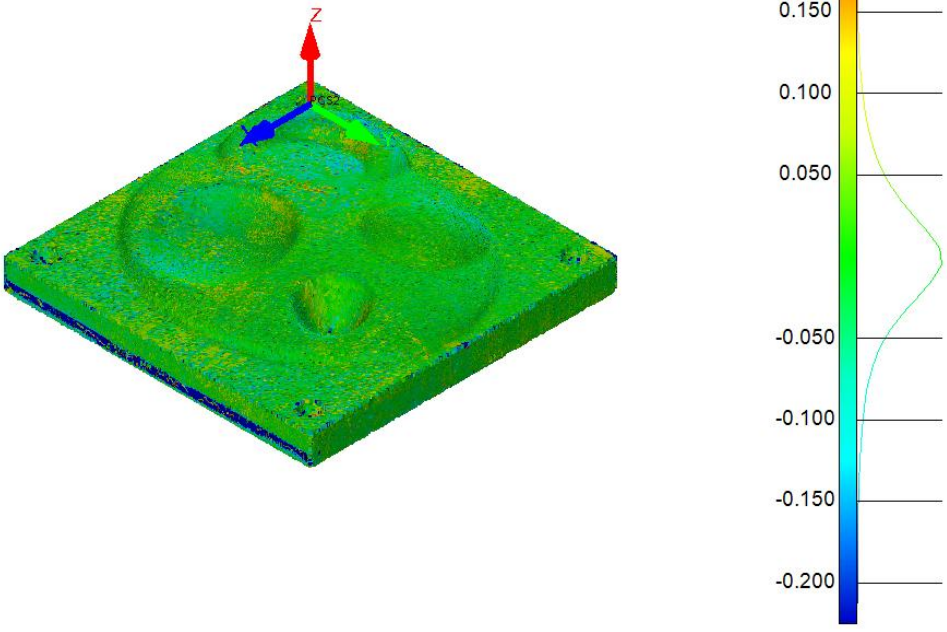
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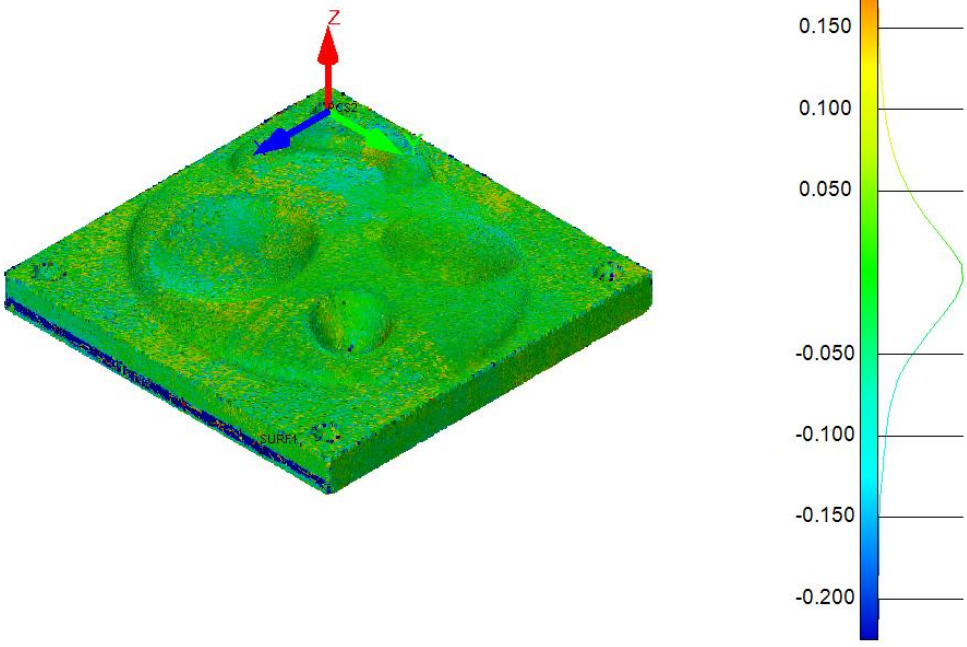
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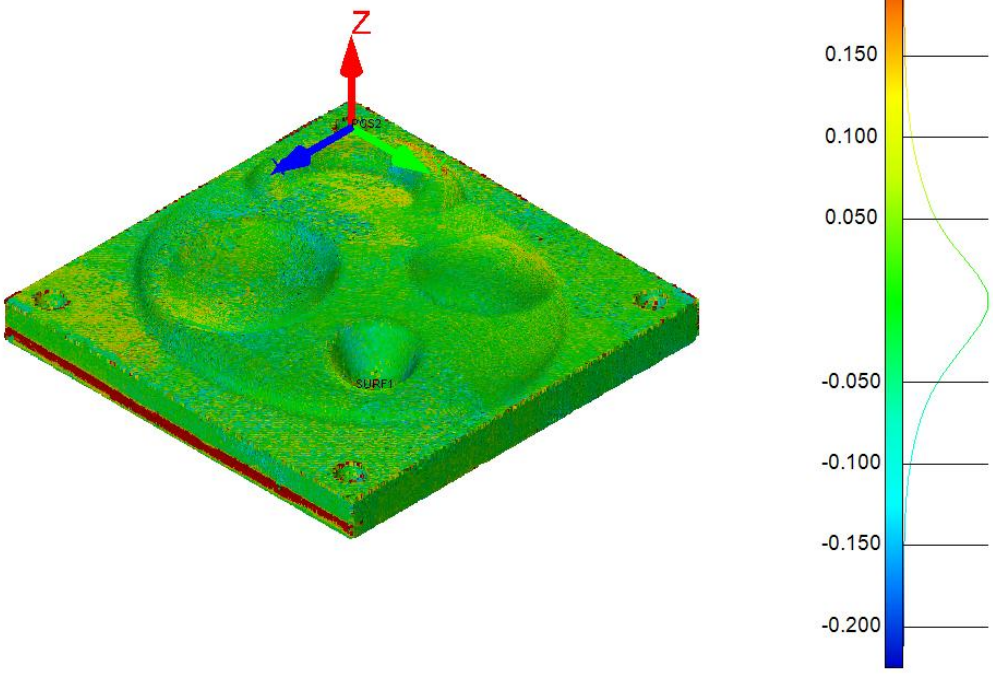
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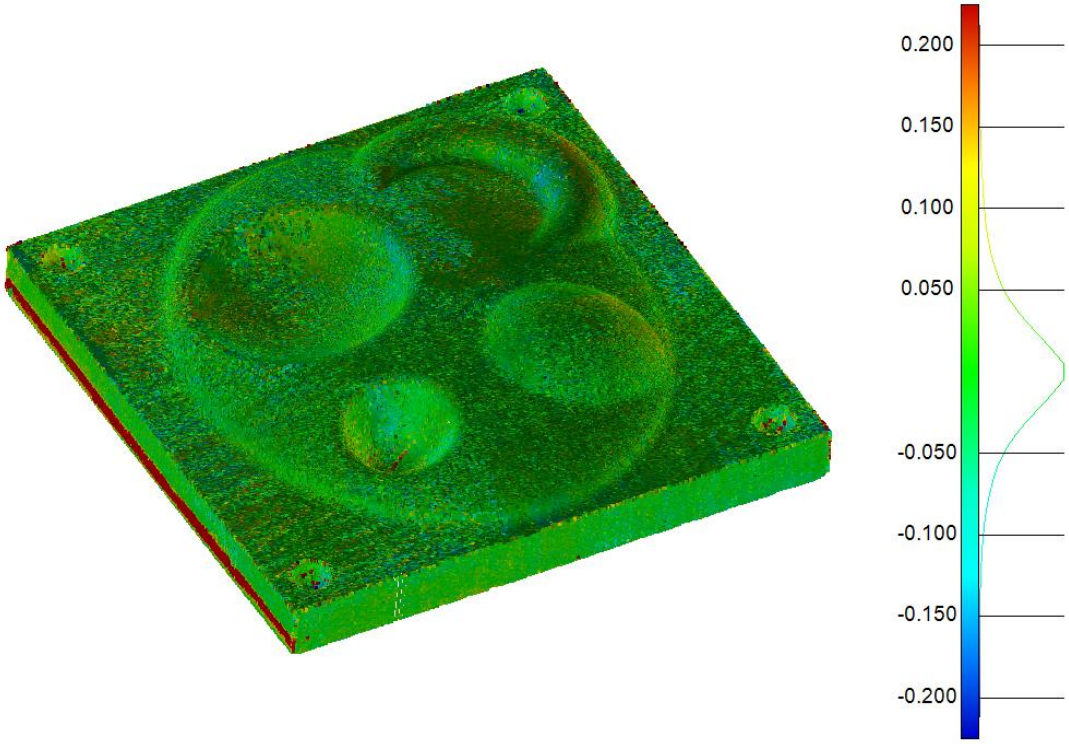
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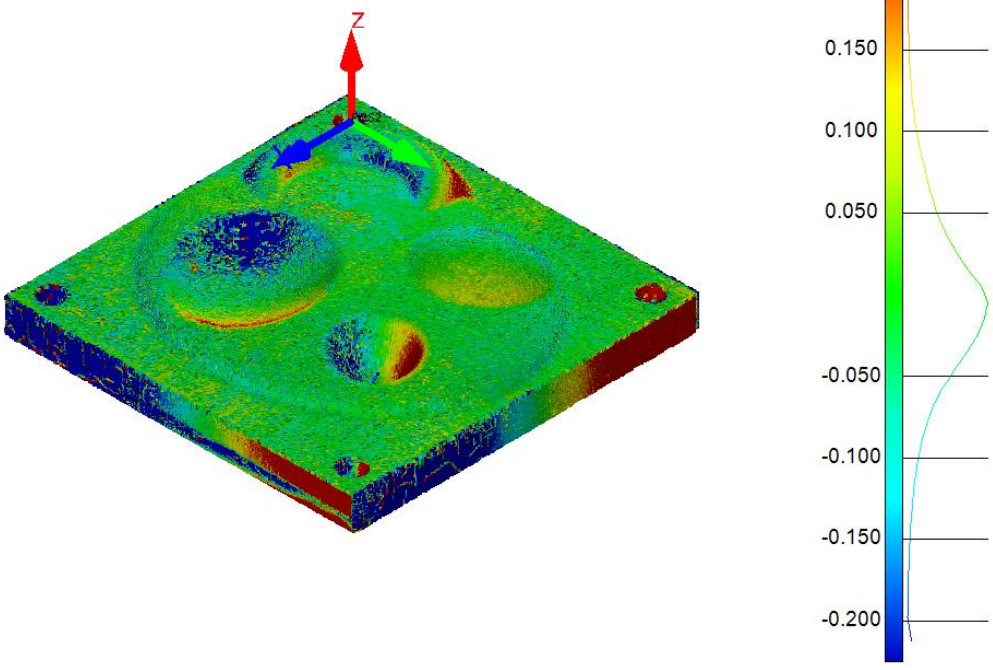
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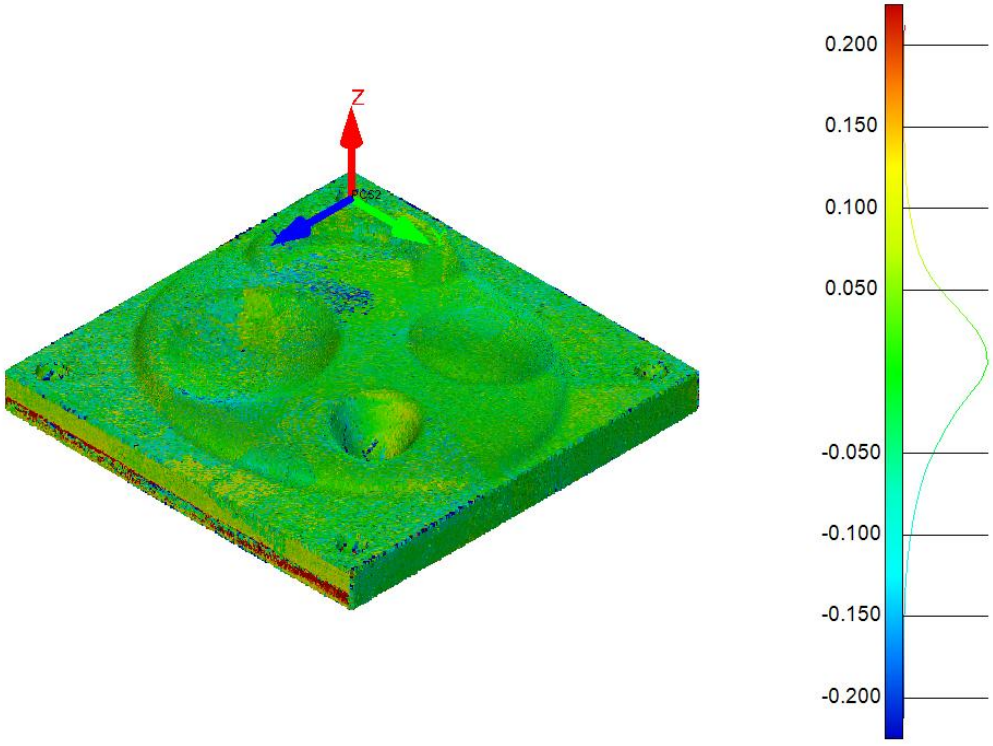
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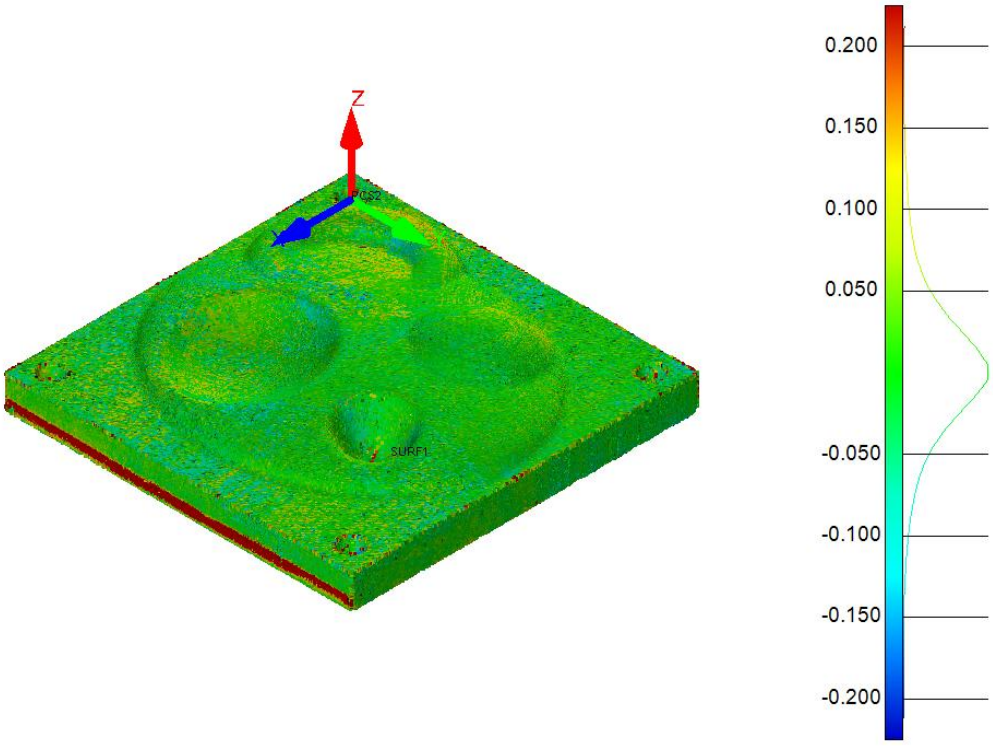
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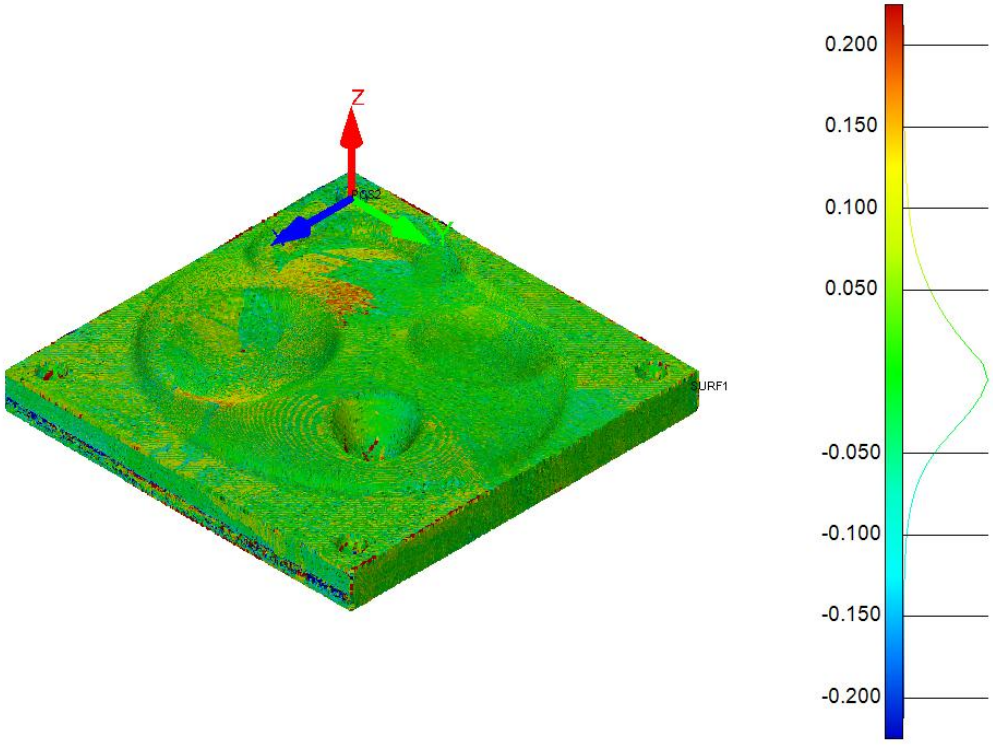
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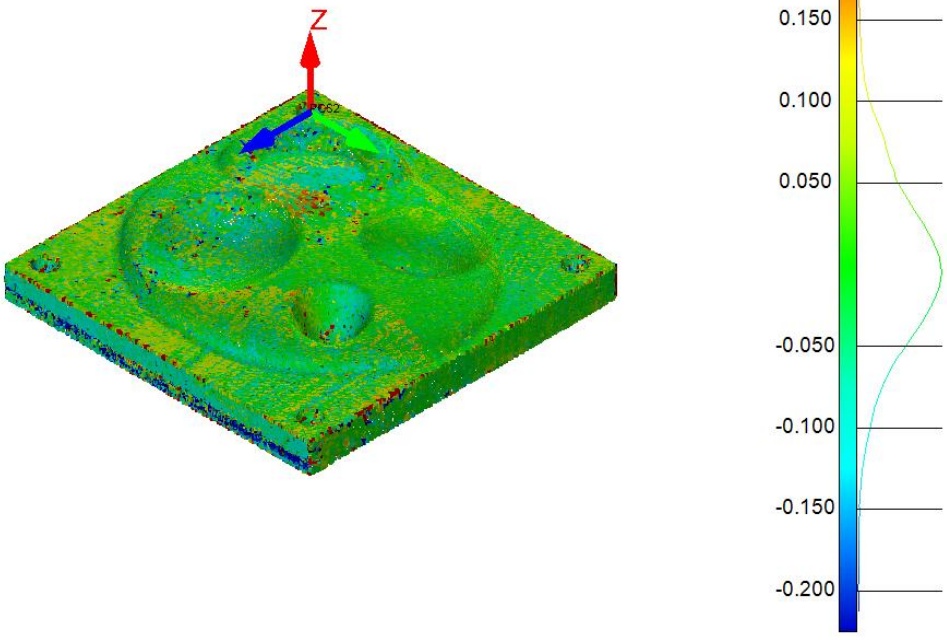
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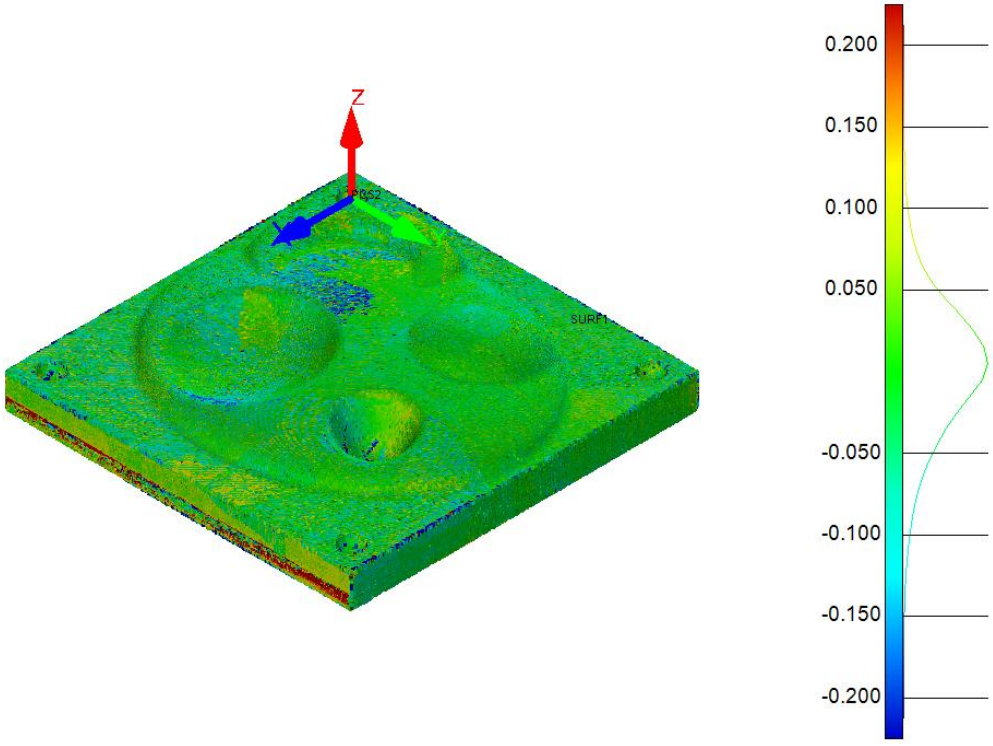
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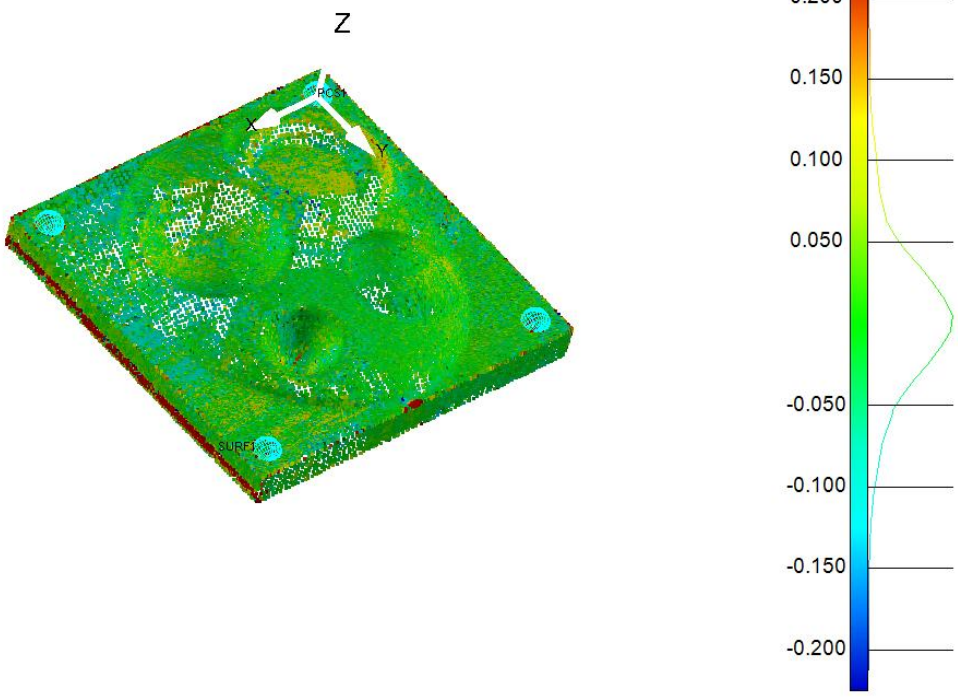
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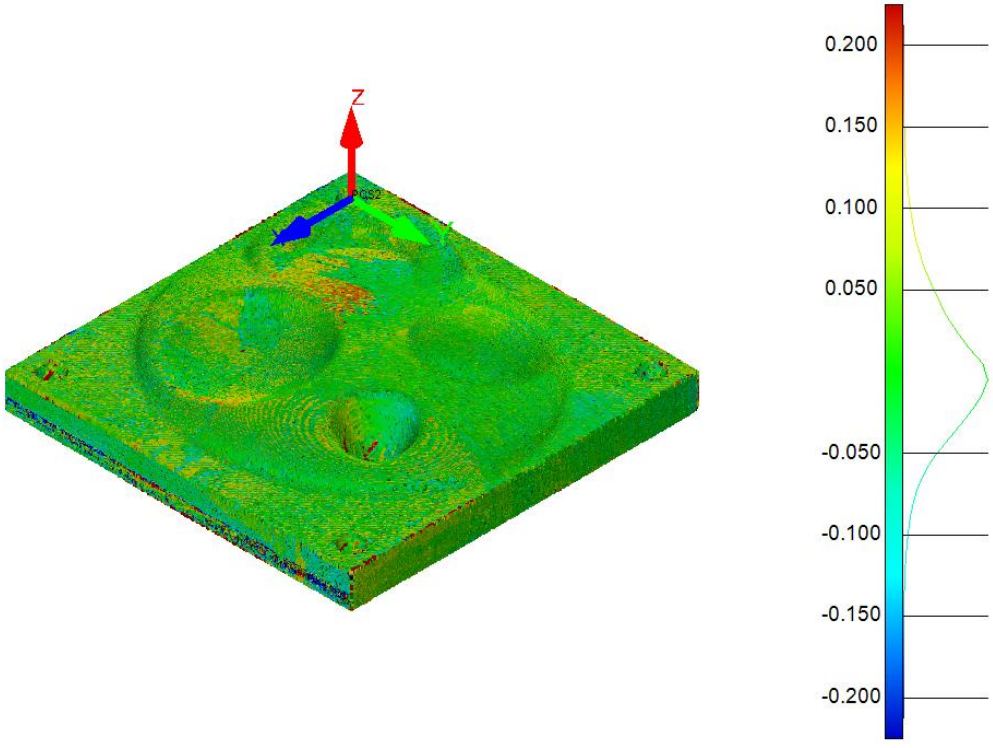
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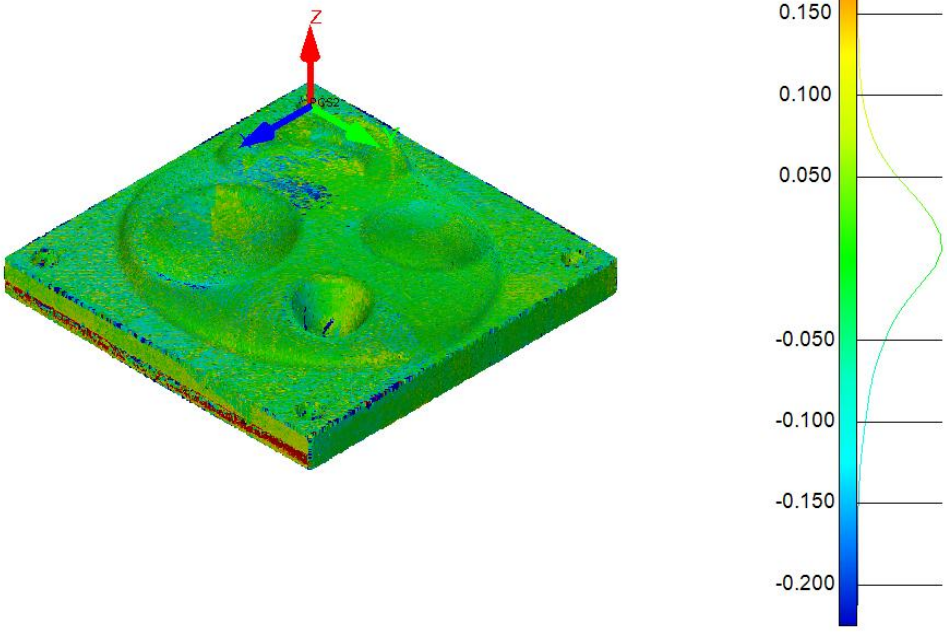
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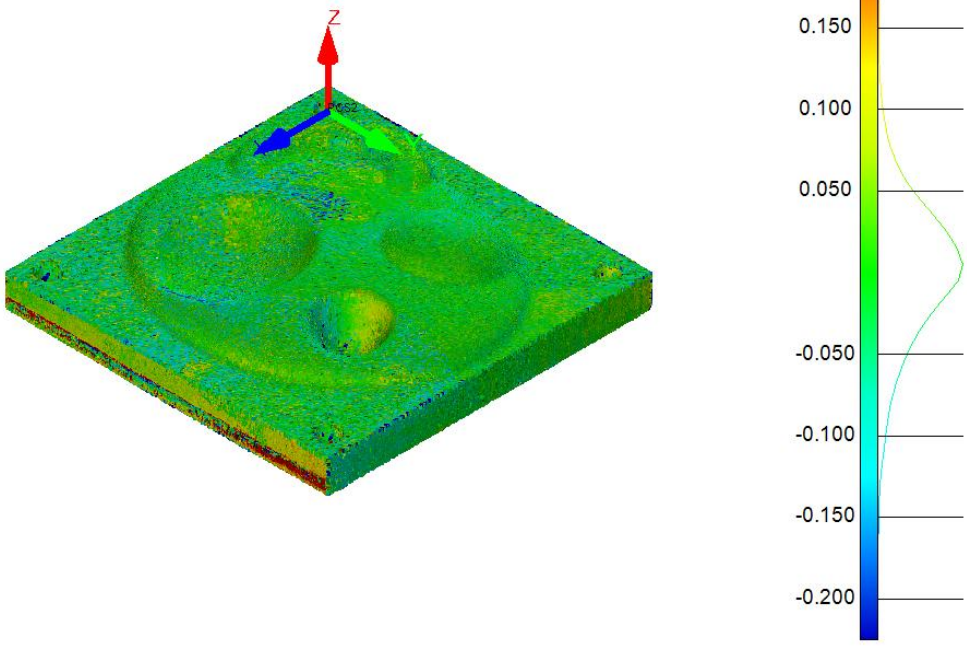
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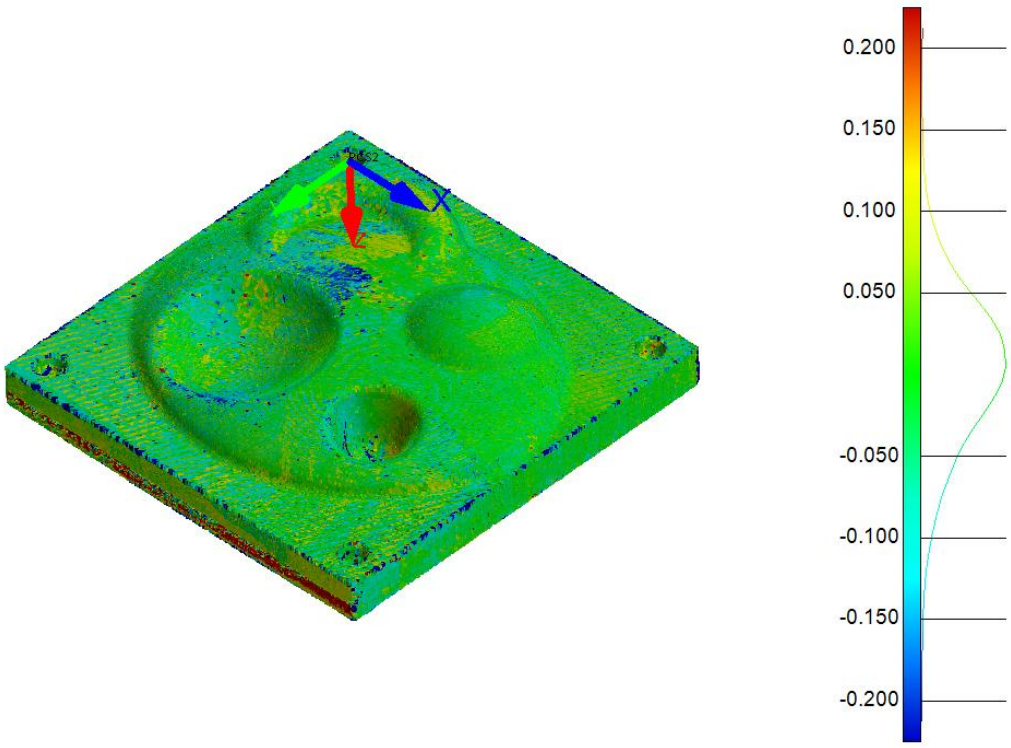
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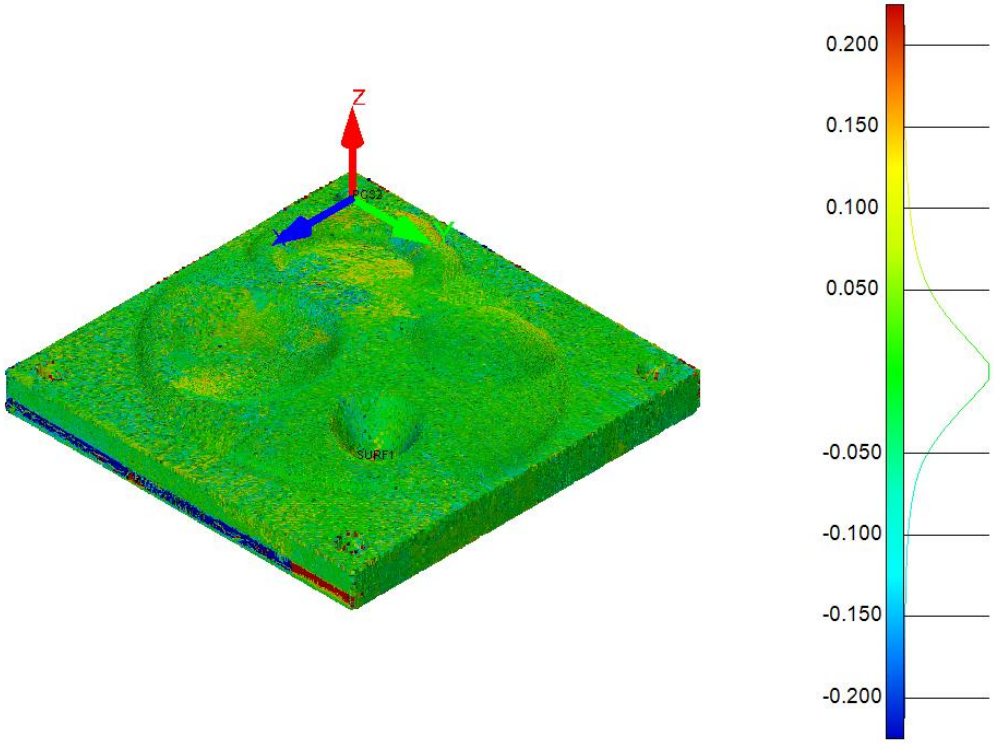
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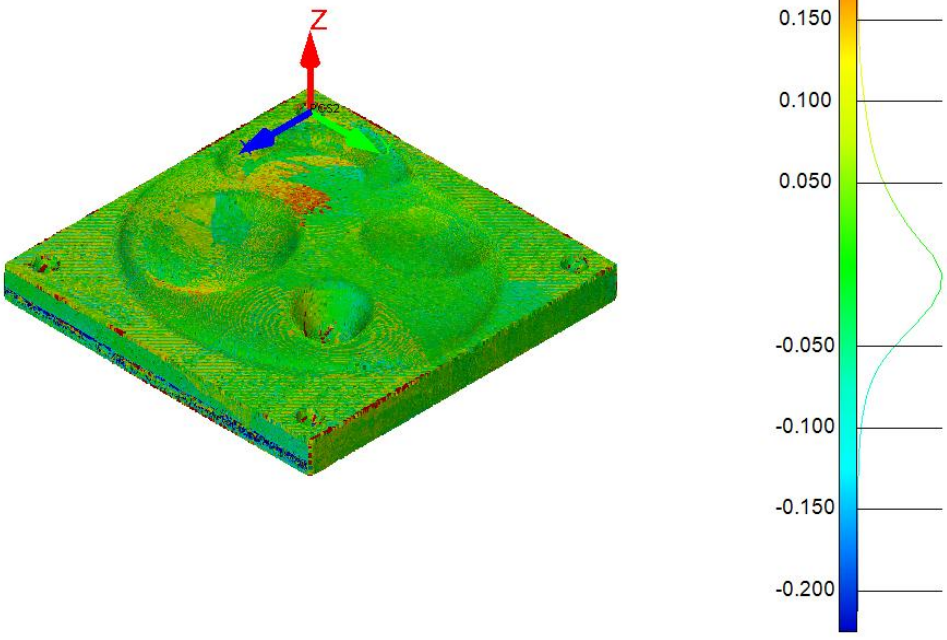
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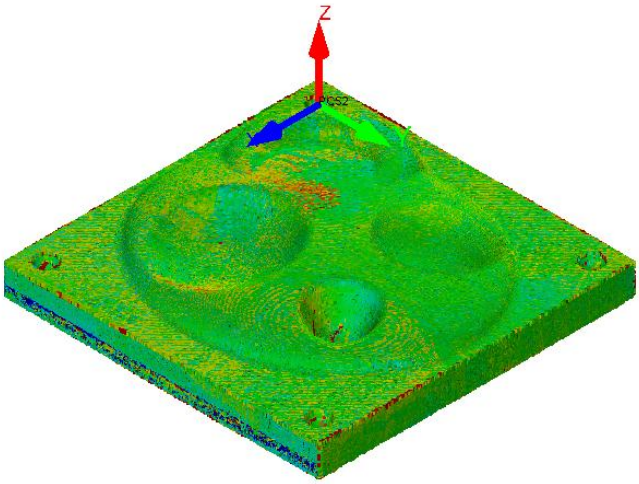
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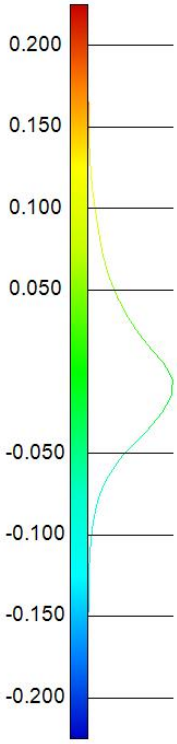
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0.100
0.050
-0.050
-0.100
-0.150
-0.200

SUMMARY

The following sections summarize the demographics, selection choices, parameters, evaluation data and observations obtained during the study.

Demographics of Participants

The following sections gives the highlights of Demographic, selection choices, parameters and evaluation data obtained during the study.

1) Industrial sectors ranged from:

- Aerospace, NMI, Heavy Industry, Automotive, Design and education

2) Job roles ranged from:

- Quality, scientist, engineer, manufacturing, metrology, management

3) Age ranged from 18 to 59:

- 18 to 39 - 35%
- 40 to 59 - 65%

4) Experience:

- 0-5 years - 65%
- 6 to 10 years - 15%
- 21 or more - 20%

5) Frequency of measurements ranged from:

- Never - 30%
- Occasionally - 20%
- Weekly - 50%

6) Participated in the 2012 study:

- 20% participated in the prior year's study

7) Training ranged from:

- Apprenticeship
- Community Technical college
- Specialized training programs

Selection Choices During Tasks

1) Offline: Filtering before the mesh

- Grid filter before mesh - 10%
- Uniform filter before mesh - 60%

2) Offline: Filtering applied to second point cloud, to be compared to previous mesh

- Grid filter - 16%
- No filter - 36%
- Uniform filter 48%
- Random filter 4%

3) Filter Method Choice

- Best Guess - 20%
- Based on Knowledge - 80%
- Participants who chose the same filtering method for both sets of point clouds: 32%

4) Online

- Grid filter - 0%
- Uniform filter - 50%
- Random filter - 20%
- Cad proximity filter - 100%

5) Alignment choices

- 1 - 30%
- 2 - 10%
- 3 - 0%
- 4 - 10%
- 5 - 20%
- 6 - 30%

6) Units

- Millimeters - 40%
- Inches - 60%

7) Evaluation - Importance rating (where 1 is low and 5 is high)

- Importance of decision making when measuring or analyzing data
- Importance of individual certification
- Practical test challenging

All rated between 4 and 5

Observations

PCMM Observations

EXPERIENCE LEVEL	
1. Beginner to Measurement - 32% 2. Beginner to non-contact scanning with a PCMM - 20% 3. Some experience of non-contact scanning with a PCMM - 8% 4. Experienced in non-contact scanning with a PCMM - 20% 5. Not identified - 20%	
ENVIRONMENTAL CHECKS	
User inquires about **Temperature**	a) Yes - 23% b) No - 77%
User inquires about other **Environmental issues**	a) Yes - 26% b) No - 74%
WORK AREA CHECKS	
Regarding the part **Stability** and **Fixturing**, did the participant:	a) Simply ask about it - 20% b) Make sure the part was stable then (re)measured the part - 39% c) Ignore that aspect - 39% d) Correct the stability half way through the task without re-measuring features measured prior? 3%
EQUIPMENT CONSIDERATIONS	
Did the participant ask about: **Device uncertainty/precision**?	a) Yes – 46% b) No - 54%
Did the participant ask about: **Device calibration**?	a) Yes - 29% b) No - 71%
Did the participant ask about: **Device stability**?	a) Yes - 48% b) No - 52%
Did the participant ask about: **Optical scanner calibration /qualification**?	a) Yes - 22% b) No - 78%
Did the participant inquire about the position of the part relative to the device (to check **reachability**)?	a) Yes - 40% b) No - 60%
Did the participant have questions about the **Tolerances** displayed on the screen?	a) Yes - 68% b) No - 32%
Does the participant inquire about how to position/hold the scanner relative to the surface probed?	a) Yes - 84% b) No - 16%
Does the participant ask about how close they should be from the intended point?	a) Yes - 85% b) No - 15%

Did the participant ask about the **point density** settings before the measurement began?	a) Yes - 36% b) No - 64%
Did the participant try to collect points all over the surface?	a) Yes- 85% b) No - 15%
Did the participant ask about the speed of data collection?	a) Yes - 36% b) No- 64%
SCRIPT	
Did the participant ask about **filtering** requirements?	a) Yes - 76% b) No - 24%
Did the participant ask about **point cloud spacing** requirements?	a) Yes- 58% b) No - 42%
Did the participant inquire about the **datum features**?	a) Yes - 75% b) No - 25%
Did the participant inquire about the **alignment method**?	a) Yes - 84% b) No - 16%
Did the participant ask about **what features** needs to be measured?	a) Yes - 77% b) No - 23%
Did the participant ask about the **sequence of the measurements**?	a) Yes- 32% b) No - 68%
AFTER	
Did the participants inquire about the **results**?	a) Yes - 87% b) No - 13%
Did the participant **repeat** any doubtful **measurements** or ask for the measurement to be repeated?	a) Yes - 28% b) No - 72%
Did the participant identify the reason for repeating measurement (such as: form error, measurement error, wrong feature measured, etc)?	a) Yes - 28% b) No - 72%
Other observations (if any) • Analysis decisions difficult for beginners • Good questions asked • Skipped demographic questions by accident • Aggressive filters • Excellent observation on invalid overall setup and environment • Expected device to be in specification • Saw tag on datum surface said it needed to be removed • Saw printing or etching on top surface and used large plane exclusion to avoid miscalculation • Bumped stand and realized so re-measured	

Observations (cont.)

Data Analysis Observations

EXPERIENCE LEVEL	
1. Beginner to Data Analysis – 42% 2. Some Experience of Data Analysis – 42% 3. Experienced in Data Analysis – 16%	
QUESTION	**AVAILABLE ANSWERS**
Did the participant inquire about the requirements?	a) Yes - 65% b) No - 35%
Did the participant have questions about the **Filtering requirements?**	a) Yes - 57% b) No - 43%
Did the participant ask about **point cloud spacing** requirements?	a) Yes - 58% b) No - 42%
Did the participant trap **enough** of the feature to get a valid result?	a) Yes - 93% b) No - 7%
Did the participant trap **too much** of the feature to get a valid result?	a) Yes - 31% b) No - 69%
Did the participant inquire about the **alignment method**?	a) Yes - 46% b) No - 54%
Did the participant enquire about the **tolerancing** requirements?	a) Yes - 38% b) No - 62%
Did the participants inquire about the **result** of the data that was analyzed?	a) Yes - 73% b) No - 27%
Did the participant ask to **repeat** any doubtful **calculations**?	a) Yes - 46% b) No - 54%
Other observations: • Aborted autofit due to time • Restarted fit with reduced data • Enquired about scaling • Mesh spacing unknown so left all data filtered at the beginning • Zoomed in to specify points • Thought about repeating mesh • Only filtered at the beginning because thought could only do it at that stage • Participant noticed results were bad but decided not to repeat calculations • Picked outside spheres • Went back and repeated calculations • Area for Selection of points varied across participants	

Measurement Workshop

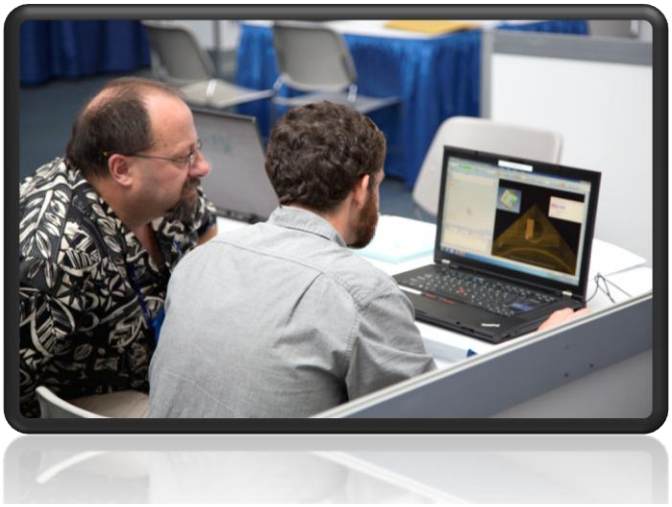
On the third day of the study, an overview covered previous measurement studies and an interim report on the data obtained from the previous 2 days. In addition, Dr. Michael McCarthy from the National Physical Laboratory gave an overview on Metrology tips on Fringe projection, laser scanner and software observations.

CONCLUSION

After completion of the measurement study, the same key areas identified in the previous two studies from 2010 and 2011 were identified as important. The significance of the requirements of pre-measurement, measurement planning, obtaining the measurement and the post measurement criteria was highlighted during both days.

Knowledge and understanding of the following fundamentals is key to support a good measurement strategy, incorporating good measurement practice, and using the proper behavior as part of the measurement to reduce the variation and uncertainty about the results.

- Don’t assume
- Ask questions
- Knowledge needed to make informed choices when both measuring and analyzing data
- Repeat any doubtful calculations
- Be careful when ‘trapping’ information to make informed calculations
- Ask questions about the device, setup, part alignment and tolerance requirements
- Importance of decision making when measuring or analyzing data
- Importance of individual certification



In conclusion, the measurement study outcomes have highlighted the importance of knowledge, understanding, and the practical testing of the key measurement areas enabling an individual to make informed judgments about the measurement. Whether it be a physical measurement or a data analysis task, questioning and planning all the requirements of the measurement will contribute to reducing the possibility of poor measurements and incorrect data analysis.

APPENDIX A

CMSC 2009 Certification Development

In 2009, the CMS certification committee was formed to study the need for 3D Portable Metrology Certification. The remit was to research existing certifications, survey the CMS membership (2009 conference) and to develop a preliminary Body of Knowledge (BOK). An Established Charter was developed that defined the committee membership, the reporting responsibility and updated CMS bylaws to make certification committee a standing committee.

The original assumptions were to justify the need that equipment operators and data processors are the target audience. CMS investigated a partnership in administering certification and that training would be provided by 3rd party organizations such as manufacturers, service providers, academia, and national institutes.

Conclusions Drawn from 2009 Study

- A properly structured certification program would be of definite value.
- Currently equipment must be calibrated, but the operator, the greatest potential source of error, is not required to be certified.
- Certification should be multi-level to delineate degree of capability and responsibility.
- Certification should indicate mastery of a core body of knowledge with additional certifications for equipment/software.
- Hardware/software certification should demonstrate appropriate technical knowledge as well as proficiency.
- There should be certified examiners for each hardware group.
- There may be areas where certification would be application specific.

CMSC 2010 Skills Development

The CMS certification committee developed the idea to perform a statistical study at CMSC. The aim of the study would identify skill gaps in the general metrology community. In addition to this, the workshops at CMSC would relate content to data developed in the study.

The CMSC 2010 study was an open measurement workshop inviting conference delegates to participate in a measurement study. The subject of the measurement study was based on a variety of ‘hand tools’ used in dimensional measurement. The studies objectives were to look at the importance of:

- Core measurement principles
- Instilling the right measurement strategy
- Observing behavior when dealing with measurements
- Instilling a questioning culture

CMSC 2013 Measurement Study Report

The measurement studies were to be undertaken over 2 days in 2 separate areas using various defined first principle tasks.

The criteria of the tasks were modified to allow for various training & assessments techniques to be undertaken such as:

- Assessment of prior learning and experience
- Questioning techniques
- Practical task monitoring
- Demonstration

2011 and 2012 Measurement Studies

Since 2011, the measurement study theme has varied and addressed:

- How Behavior Impacts your Measurement in 2011
- The Importance of Practical Testing in 2012

CMS Members can read about the strategy of these studies and the resultant data in the Measurement Study Reports found online at www.CMSC.org.

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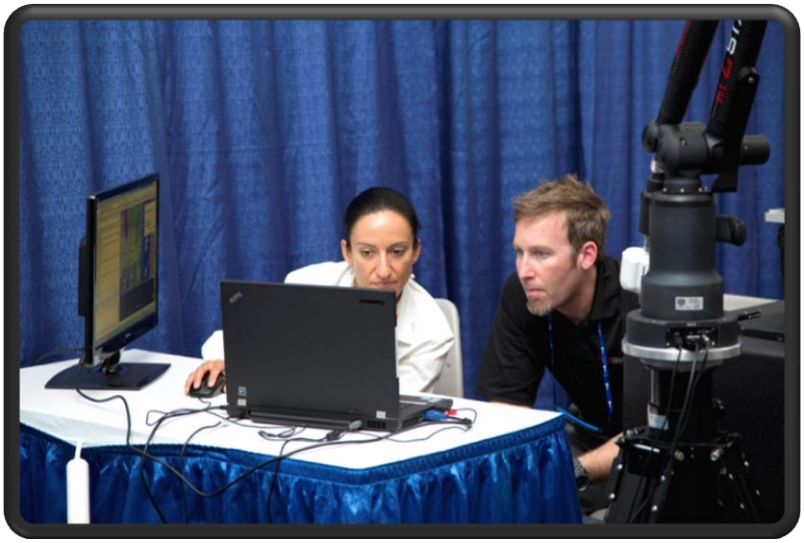

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