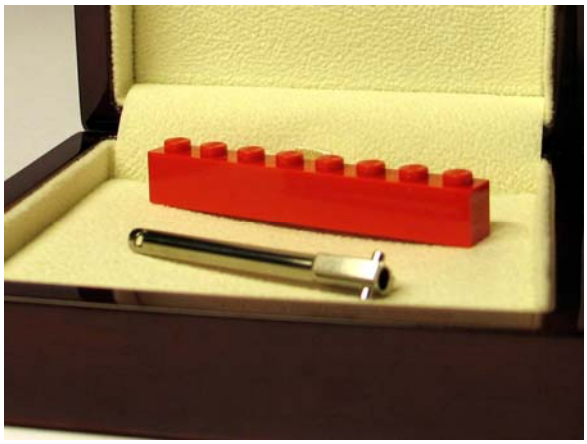
CIA-CT comparison

Inter laboratory comparison on Industrial Computed Tomography



Technical Protocol

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J. Angel, L. De Chiffre, E. Larsen, J. Rasmussen

Department of Mechanical Engineering

Technical University of Denmark

1. Introduction

The 'CIA-CT comparison - Inter laboratory comparison on industrial Computed Tomography" is organized by DTU Department of Mechanical Engineering within the Danish project "Centre for Industrial Application of CT scanning - CIA-CT". The project is co-financed by the Danish Ministry of Science, Technology and Innovation.

The comparison aims to collect information about measurement performance in state-of the-art industrial CT (Computed Tomography) scanning. Since CT scanning has entered the field of manufacturing and coordinate metrology, evaluation of uncertainty of measurement with assessment of all influence contributors has become the most important challenge related to the establishment of measurement traceability. This investigation focuses mainly on operator influences on the measurement result.

Two items are used, selected among common industrial parts: a polymer part and a metal part.

The items are measured by 25 participants from different countries.

The main goals of the project can be summarized as follows:

- To test applicability of CT scanning for measurement on small objects commonly measured in industry, which are less accurate and stable than reference artefacts.
- To evaluate the impact of instrument settings and operator decisions on the measurement of items of two different materials and geometries.
- To investigate measurement errors and their causes.
- To collect and share knowledge on practical aspects related to the traceability of measurements using industrial CT scanning.

The following outcome is expected:

- Different procedures for performing the same measurement tasks are discussed.
- Different parameter settings for performing the same measurement tasks are discussed.
- Measurements and uncertainty models are illustrated and discussed.
- Each participant will after the comparison and re-calibration keep the items and be able to use them as reference objects for future use.
- A set of two industrial items with calibration procedures will be available for future comparisons.

The results from each participant are kept confidential.

2. Participants details

Num.	Participant	Contact person	Country
1	**3D-CT A/S**	Kim Mortensen	Denmark
2	**BAM Federal institute for materials research and testing**	Karsten Ehrig	Germany
3	**Carl Zeiss IMT GmbH**	Ecaterina Schuster - Fabian	Germany
4	**Chair of Manufacturing Metrology, Friedrich-Alexander-University Erlangen-Nuremberg (QFM)**	Tino Hausotte	Germany
5	**Danish Technological Institute (DTI)**	Peder Pedersen	Denmark
6	**Fraunhofer Development Center for X-ray Technology (EZRT)**	Stefan Kasperl	Germany
7	**GE Measurement & Control (Zebicon A/S)**	Kim Demant Andersen	Denmark
8	**GRUNDFOS A/S**	Lars Øster	Denmark
9	**Hexagon Metrology Inc**	Jonathan O'Hare	USA
10	**Huddersfield University (HUD)**	Paul Bills	United Kingdom
11	**Katholieke Universiteit Leuven**	Tan Ye	Belgium
12	**LEGO System A/S**	Per René Schmidt	Denmark
13	**National Metrology Institute of Japan, National Inst. of Advanced Ind. Science and Technology**	Hiroyuki Fujimoto	Japan
14	**National Physical Laboratory (NPL)**	Richard Leach	United Kingdom
15	**Nikon Metrology UK**	David Bate	United Kingdom
16	**Novo Nordisk A/S, Device R&D**	Jan Lasson Andreasen	Denmark
17	**Novo Nordisk A/S, DMS Metrology & Calibration**	Trine Sørensen	Denmark
18	**Physikalisch-Technische Bundesanstalt (PTB)**	Markus Bartscher	Germany
19	**SGS Institut Fregenius GmbH**	Thomas Fox	Germany
20	**SIMTech**	Joseph Lifton	Singapore
21	**University of Padova (UNIPD)**	Simone Carmignato	Italy
22	**University of Southhampton**	Ian Sinclair	United Kingdom
23	**YXLON International GmbH**	Frank Herold	Germany
24	**Wenzel Volumetrik GmbH**	Martin Simon	Germany
25	**Werth Messtechnik GmbH**	Martin Heath	Germany

3. General instructions

1. This technical protocol has been prepared by DTU Mekanik - CGM. It contains general information as well as details on participants, artefacts, circulation, and reporting.
2. The comparison is based on a set of two items for each participant.
3. All sets of items are circulated in parallel, one set of items to each participant, in order to complete the circulation in 1 month, and 12 months from project start to final report.
4. Each participant is expected to measure the items and report the results. The measurement results shall be reported in English, including measurement uncertainties.
5. Measured values from each participant will be compared with reference values obtained by the coordinator using a tactile coordinate measuring machine (CMM).
6. The coordinator will analyse all participants' results and prepare a draft report for distribution to all participants. E_n-values will be made available to the participants by the coordinator.
7. In the report, the ID of the participants will be coded so that it is not possible to identify the name of the participants. The identification of a participant will be made available only to the participant.
8. The time plan for the entire comparison is shown in figure 1. The items will be distributed (circulated) in week 2 to 4 (7th January to 27th January) 2013 and are to be sent back to the coordinator by 28th January 2013. The results from the participants are expected no later than February 22nd. The deadlines should not be exceeded.

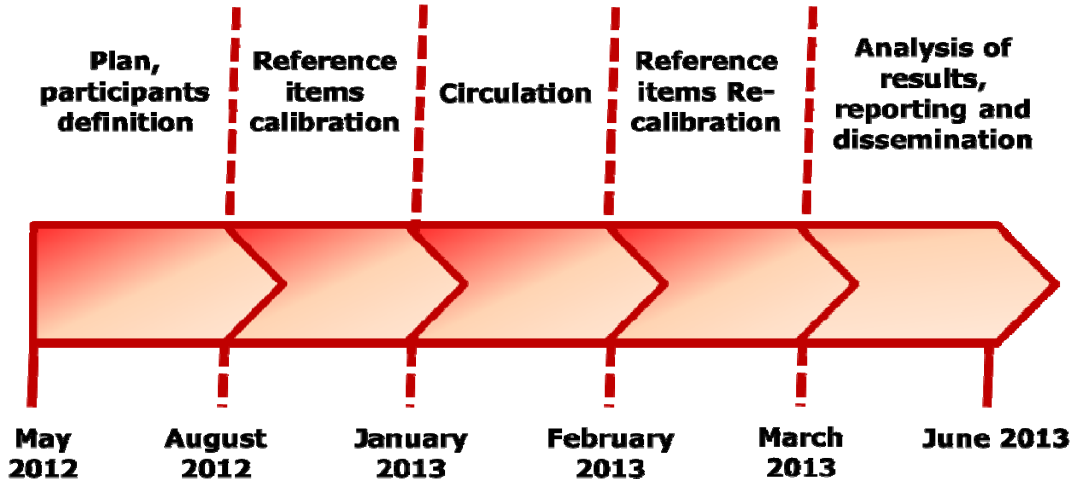

Figure 1: Time schedule for the comparison.

4. Items to be measured

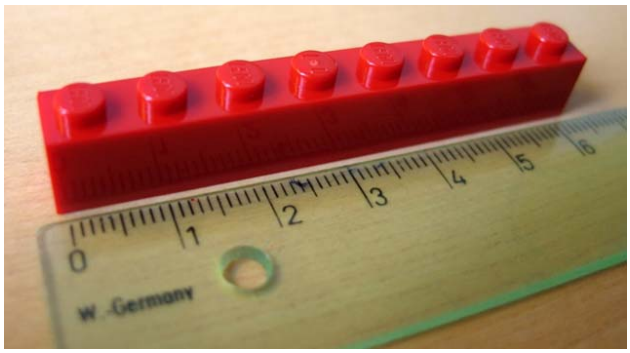

Figure 2: Item 1 (Lego brick).

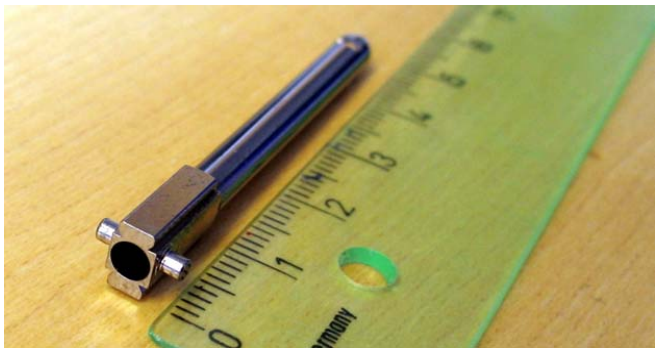

Figure 3: Item 2.

Item 1 is a polymer brick from LEGO. The item is made of Acrylonitrile Butadiene Styrene (ABS) featuring eight knobs in one row as shown on Figure 2. **Item 2** is a metallic tubular component from the medical industry. Item 2 is shown in Figure 3.

5. Handling and circulation instructions

The items are contained in a box. The items and the box should be handled with care. Pictures of the box and the items can be seen in figures 4 and 5.

Please use gloves when handling the items.

Figure 4: External box for storage and transportation of the items.

Figure 5: Internal box containing the two items.

1. Immediately upon receipt, the items must be examined and their conditions communicated by e-mail to the coordinator. Please note that the items have been glued in connection with reference measurements. Glue deposits can be ignored.
2. The items must only be handled by authorised personnel and treated in order to prevent damages.
3. The measuring time for each participant is three weeks including shipping back to the coordinator of the comparison.
4. Each participant is responsible for shipping the box with the items back to the coordinator. Please inform the coordinator by e-mail when the standards are about to be returned.
5. Before shipment, inspect the items accurately. Take high resolution pictures to document the status of the items.
6. Ensure that the content of the box is complete before shipment using the original package.
7. The parcel should be sent by courier to ensure quick delivery and also that the package is not lost, damaged or handled by unauthorised persons.
8. Participants are requested to produce measurement results following the procedures provided in this technical protocol. The results should, no later than February 22nd, be uploaded to a FTP server provided by the coordinator.

6. Measurement instructions

Participants are expected to measure both items and produce results. Measured values and stated uncertainties from each participant will be compared with reference values and uncertainties obtained by the coordinator.

Dummy CAD models (STEP) are provided to participants by the coordinator.

6.1. Item 1

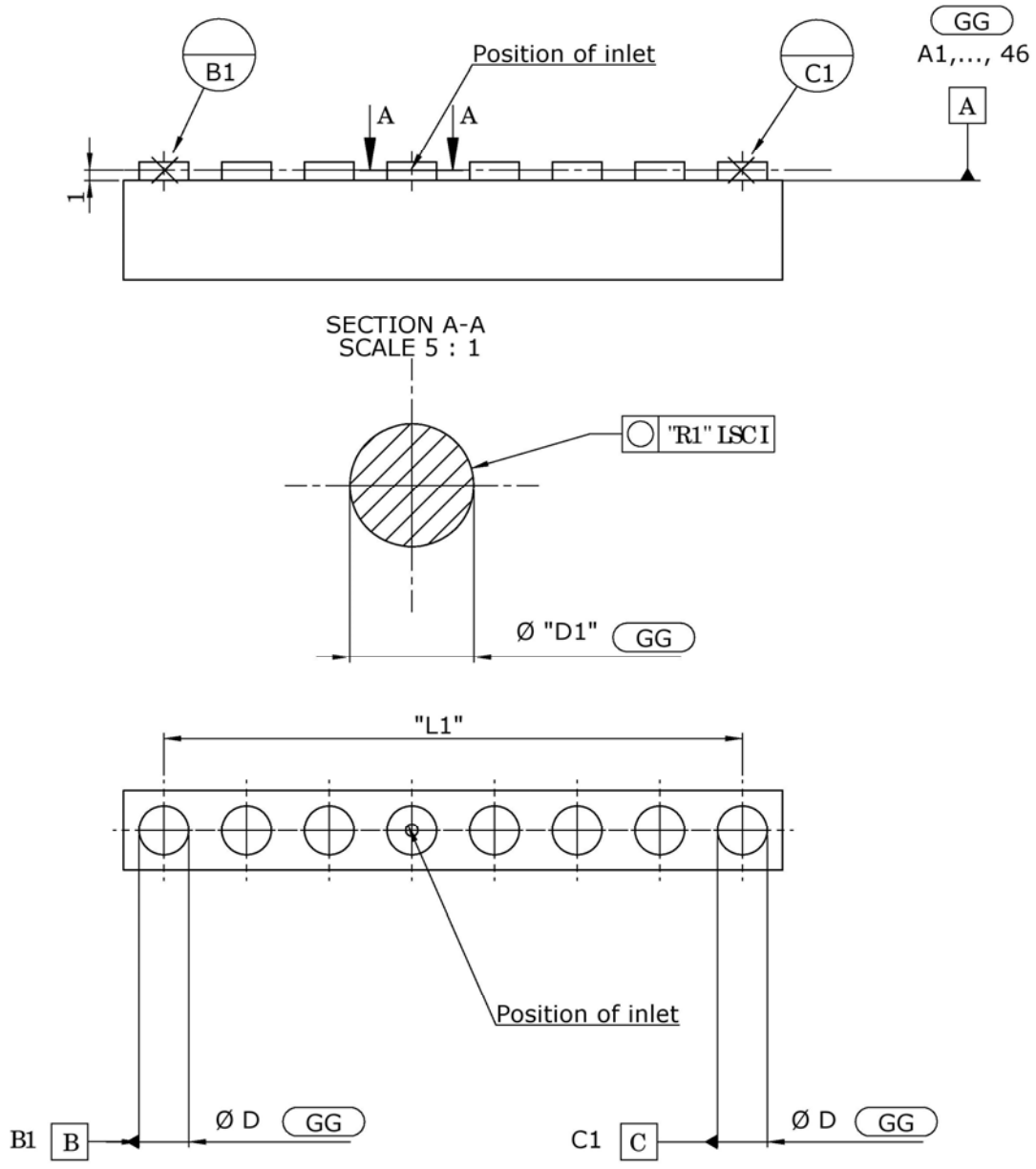

Figure 6: Measurement details for Item 1. Sketch not to scale.

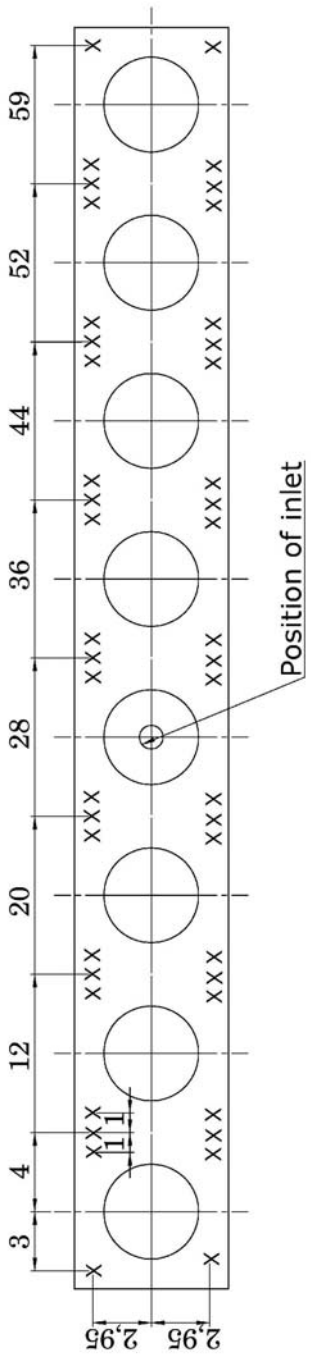

Figure 7: Position of datum [A] points for Item 1. Sketch not to scale.

6.1.1. Preparations for Item 1

It is recommended to clean Item 1 gently using compressed air and/or a soft brush. A fixture can be selected at own choice.

6.1.2. Datum system to be used

Alignment	Identification	Description
Primary (Spatial alignment)	Datum A	Datum A (plane) is created by a least square fitting (GG) 46 points to be used: Point no. A1 to no. A46
Secondary (Plane alignment)	Line between Datum B and Datum C	Datum B - circle (GG) is measured 1 mm above datum A Datum C - circle (GG) is measured 1 mm above datum A
Tertiary (Zero point in the third axis)	Zero point in Datum B	(Datum B above to be used)

Note: (GG = Least Square Element as defined in ISO 14405-1 [1]).

6.1.3. Measurands and measuring conditions

Density [g/cm^3]	Thermal expansion coefficient [10^{-6} K^{-1}]
1,040	95±15

Identification		Description
Diameter,	*D1*	Diameter of knob at inlet *D1* - circle (GG) is measured 1 mm above datum A
Roundness,	*R1*	Roundness of knob at inlet *R1* - circle (LSCI) is measured 1 mm above datum A
Length,	*L1*	The distance between datum B and datum C 1 mm above datum A

Note: (GG = Least Square element as defined in ISO 14405-1 [1]).
Note: (LSCI = Least Square Circle as defined in ISO 12181-1 [2] and -2 [3]).

6.1.4. Reporting

The attached report template should be used for reporting. All measurements must refer to 20ºC.

Please report the measured values of ***D1*, *R1* and *L1*** together with their measuring uncertainties at 95% confidence level (*k*=2).

It is also asked to report, together with measurement results, acquisition parameters (scanning parameters, e.g. use of hard filter, ROI scan) and processing parameters (e.g. beam hardening correction), and to send raw CT data (e.g. .vgi), processed data (e.g. .vgl) and .stl files if relevant, to the coordinator for further investigations.

Please, also provide polar plots of the circle from which ***D1*** and ***R1*** are calculated, for the unfiltered profiles as well as for profiles filtered using 50 UPR (undulations per rotation) and 150 UPR.

Take pictures of the CT scanner with the item placed on the rotary table showing the fixture used for supporting the item. Describe the material and shape of the fixture, including its density. Please also report if you have used any subsidiary instruments.

6.2. Item 2

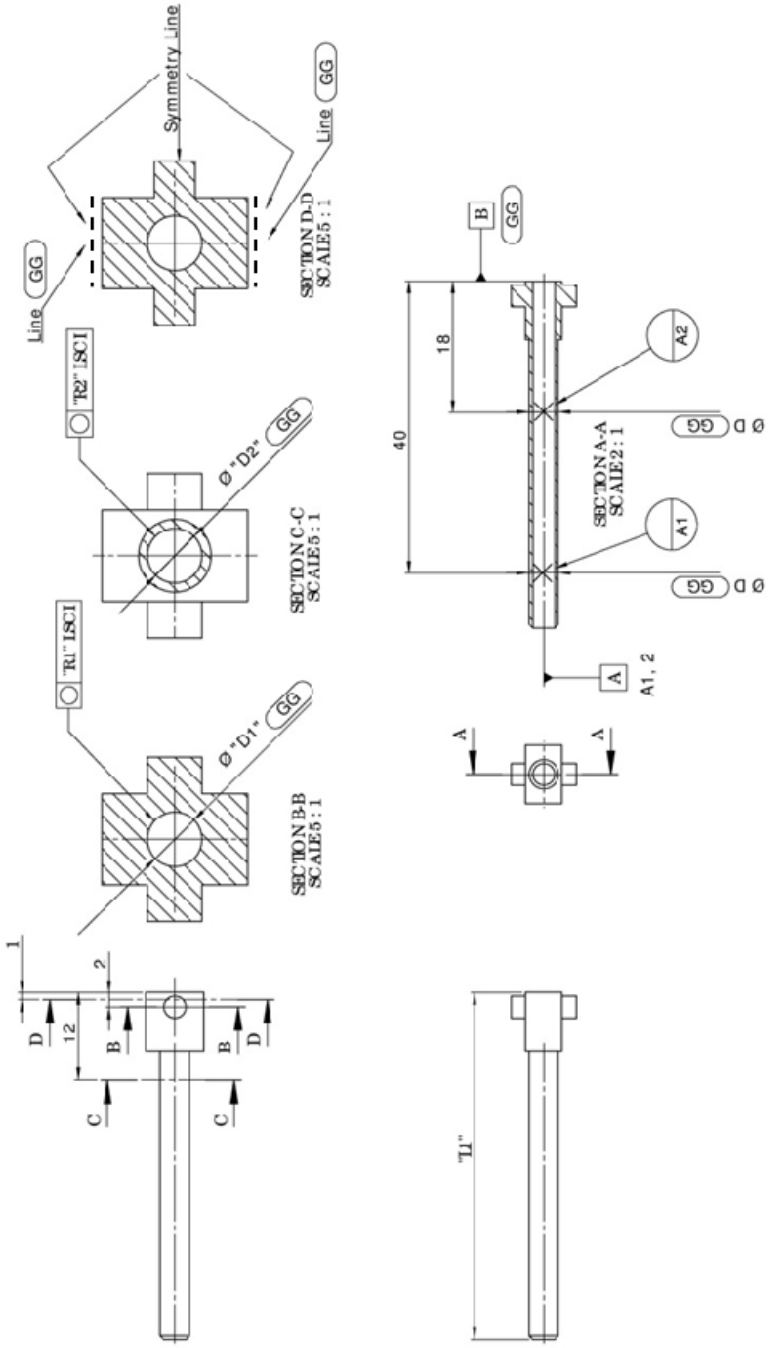

Figure 8: Measurement details for Item 2. Sketch not to scale.

6.2.1. Preparations for Item 2

It is recommended to clean Item 2 carefully using compressed air and/or a soft brush. Additionally, the use of de-greasing liquid is also allowed. A fixture can be selected at own choice.

6.2.2. Datum system to be used

Alignment	Identification	Description
Primary (Spatial alignment)	Datum A	Datum A (axis of outside cylinder) is created by a least square fitting (GG), between center of circle datums A1 and A2, both GG
Secondary (Plane alignment)	-	Symmetry line based on two lines (GG) in section D-D, 1 mm from Datum B
Tertiary (Zero point in the third axis)	Zero point on Datum B	Plane (GG) – Intersection point between Datum [A] and plane measured as (GG)

Note: (GG = Least Square Element as defined in ISO 14405-1 [1]).

6.2.3. Measurands and measuring conditions

Density [g/cm^3]	Thermal expansion coefficient [10^{-6} K^{-1}]
8,5	20±1

Identification		Description
Diameter,	D1	Internal diameter, least square fitting (GG) D1 –circle is measured 2 mm from datum B
Roundness,	R1	Roundness of internal diameter R1 – on circle (LSCI) is measured 2 mm from datum B
Diameter,	D2	Internal diameter , least square fitting (GG) D2 –circle is measured 12 mm from datum B
Roundness,	R2	Roundness of internal diameter R2 – on circle (LSCI) is measured 12 mm from datum B
Length,	L1	Total length L1 - The length between the two “GG” planes, in the axis of the primary alignment (in the centre axis of the item – intersection between axis and planes)

Note: (GG = Least Square element as defined in ISO 14405-1 [1]).
Note: (LSCI = Least Square Circle as defined in ISO 12181-1 [2] and -2 [3]).

6.2.4. Reporting

The attached report template should be used for reporting. All measurements must refer to 20ºC.

Please, report the measured values of ***D1, R1, D2, R2*** and ***L1*** together with their measuring uncertainties at 95% confidence level (*k*=2).

It is also asked to report, together with measurement results, acquisition parameters (scanning parameters, e.g. use of hard filter, ROI scan) and processing parameters (e.g. beam hardening correction), and to send raw CT data (e.g. .vgi), processed data (e.g. .vgl) and .stl files if relevant, to the coordinator for further investigations.

Please, also provide polar plots of the circles from which ***D1*** and ***R1***, as well as ***D2*** and ***R2*** are calculated, for the unfiltered profiles as well as for profiles filtered using 50 UPR and 150 UPR.

Take pictures of the CT scanner with the item placed on the rotary table showing the fixture used for supporting the item. Describe the material and shape of the fixture, including its density. Please also report if you have used any subsidiary instruments.

7. Coordinator contact information

The document is confidential and only used within the "CIA-CT" project. It is not allowed to copy or distribute any information from this document without contacting the coordinator of the project.

Coordination **Prof. Leonardo De Chiffre** **DTU Mechanical Engineering** **Produktionstorvet, building 425** **Technical University of Denmark** **DK – 2800 Kgs. Lyngby** **Denmark**	Phone: +45 45 25 47 60 (direct) E-mail: ldch@mek.dtu.dk
Administration, circulation, data analysis **Jais Angel** **DTU Mechanical Engineering** **Produktionstorvet, building 425** **Technical University of Denmark** **DK – 2800 Kgs. Lyngby** **Denmark**	E-mail: jaia@mek.dtu.dk
Reference calibration **Erik Larsen** **IPU - Technology Development** **Produktionstorvet** **Building 425** **DK – 2800 Kgs. Lyngby** **Denmark** **Jakob Rasmussen** **DTU Mechanical Engineering** **Produktionstorvet, building 425** **Technical University of Denmark** **DK – 2800 Kgs. Lyngby** **Denmark**	Phone: +45 45 25 46 19 (direct) E-mail: el@ipu.dk Phone: +45 45 25 47 67 (direct) E-mail: jakr@mek.dtu.dk
DTU web site: www.dtu.dk (Phone book) **DTU Mechanical Engineering web site: www.mek.dtu.dk** **Project web site: www.cia-ct.mek.dtu.dk/**	

8. References

[1] ISO 14405-1, 2011, Geometrical product specifications (GPS) -- Dimensional tolerancing -- Part 1: Linear sizes.

[2] ISO 12181-1, 2011, Geometrical product specifications (GPS) -- Roundness -- Part 1: Vocabulary and parameters of roundness.

[3] ISO 12181-2, 2011, Geometrical product specifications (GPS) -- Roundness -- Part 2: Specification operators.