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DESIGN OF ARTEFACT FOR THE VERIFICATION OF THE CARL ZEISS METROTOM COMPUTED TOMOGRAPH

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Abstract – Industrial computed tomography enables, unlike conventional measuring methods and systems (CMM), evaluation not only of external dimensions of an object, but also its internal structure (material's porosity). Unlike coordinate measuring machines, no international standard has been adopted for tomography devices that would facilitate smooth verification of such devices (calibration). The article describes the use of the artefact designed for the rapid verification of the Carl Zeiss Metrotom 1500 device.

Keywords: computed tomography, artefact, calibration, measurement

1. INTRODUCTION

At present, there are only few appropriately defined referential objects and procedures suitable for the assessment of accuracy of computed tomographs or for the comparison of performances of individual equipments. This situation is in sharp contrast with a contact or optical scanning system for which there are appropriate means and procedures which meet, at least partially, the ISO 10360 standard. However, this standard is not directly applicable for tomography devices. The ISO 10360 standard is adjusted to the coordinate measuring machines, for which it is possible to distinguish a part serving for the measurement of distances (a linear or rotary scale / a ruler integrated in individual axes and used to achieve a shift) and a part serving as a measurement contact or a probe (contact, laser, optical or another scanning system) [1, 4].

The only standards currently serving for the purposes of computed tomography are the German standards VDI/VDE 2630 (or VDI/VDE 2617) [1].

Verification of CT equipments accuracy is carried out using various referential objects, whereas each manufacturer assesses their products using their own artefacts [3].

In order to determine the maximum permissible entity error MPE_E, manufacturers apply their own methodologies and procedures, whereas the comparison of the obtained results is difficult to carry out.

Fig. 1 shows some of the used artefacts.

Verification of the Carl Zeiss Metrotom 1500 device is carried out using an artefact consisting of 27 balls located on the extensions made of material with the minimum thermal expansion (top left Fig. 1). After the artefact is scanned, selected distances between the balls are evaluated.

With regard to the fact that during the year certain measurements might occur requiring absolute certainty that the scanning outputs are within the maximum permissible error $MPE_E = 9+L/50$, it is advisable to use an artefact for the simple verification of the device [2].

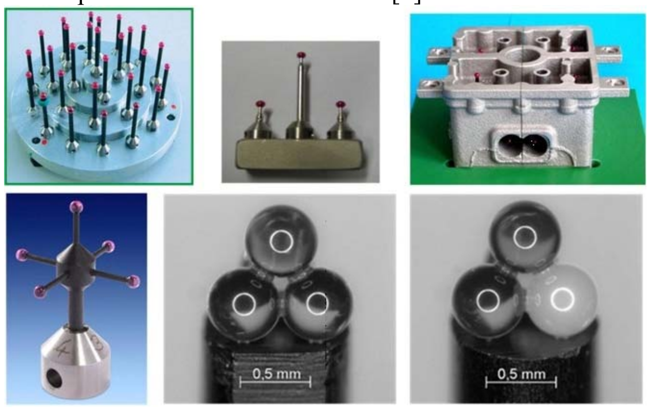

Fig. 1. Some of calibration artefacts

1.1 Metrotom 1500

This device is an industrial computed tomograph designed primarily for scanning products made of light metals (aluminium alloys) and plastic with the power of 225W. The basic system consists of an X-ray tube using a wolfram target to emit radiation. The X-ray beam is of conical shape and after the passage through a scanned object it falls onto the junction detector. Fig. 2 represents the Metrotom 1500 device and its main components – an X-ray tube, a rotary table (in the middle), and a detector (on the right).

Fig. 2. Carl Zeiss Metrotm 1500

The device has a closed structure; no additional protective equipment is thus required for the operation thereof. Basic parameters of the device are listed in Table 1.

Table 1. Parameter fo Carl zeiss Metrotom 1500 [2]

	ZEISSMetrotm 1500
Detector resolution [Pixel]	1024x1024
Detector type	Plane array
Power output [W]	225
Voltage [kV]	225
Current [μA]	1000
Spatial resolution [μA] or [line pair/mm]	8 (125 lp/mm)
Measuring volume [mm]	Φ300x350

2. DESIGN OF ARTEFACT

The artefact was designed as a simplified version of the calibration normal used by the Carl Zeiss Company for the verification of Metrotom devices.

Selection of elements for the artefact was determined on the basis of the following requirements:

- material properties – used materials must have the minimum impact on the scanning result (material density, attenuation coefficient),
- minimum thermal expansion of the used materials – to minimise dimensional changes during scanning,
- shapes of elements – they must facilitate simple reconstruction of the surface and minimise the deviations caused by the shape.

On the basis of the input conditions and currently used artefacts, an artefact was designed consisting of three probes used in coordinate measuring machines.

The artefact was assembled using probes with ball contact, whereas the contact is made of synthetic ruby and silicon nitride. The probe's body is made of carbon fibres. The probe material complies with the first and second requirement for the selection of elements. The element (a ball) which is the base for the evaluation of distances is, with regard to the aforesaid, appropriate for the evaluation. A spherical shape of the element eliminates shape deviations or errors that can result from the surface determination. Parameters of individual probes are shown in Table 2 [6, 7].

Table 2. Parameters of probes

Designation	Ball diameter [mm]	Ball material	Body material
G1	5	Ruby	Carbon fibre Trade name „ThermoFit"
G2	5	Ruby	
G3	5	Silicon nitride	

Fig. 3 represents the designed artefact. Individual probes are fixed to a base and approximately form an equilateral triangle. As for the evaluation methodology, it is not necessary to adhere to precise distances (an isosceles triangle) between individual probes, as the values obtained will be compared against each other.

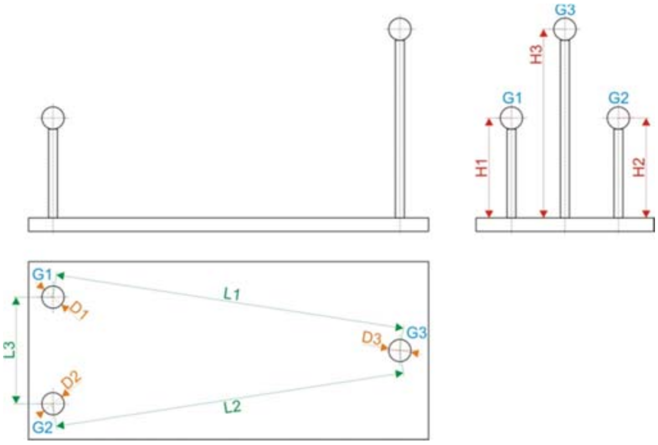

Fig. 3. Designed artefact

3. SCANNING AND EVALUATION METHODOLOGY

With the changing distance between a scanned object and the X-ray source, some of the scanning parameters change as well. Parameters which are, or can be, changing include:

- Input power– input power can change in case the distance between the object and the radiation source is short. In such case, the voxel value must be reduced, which is achieved by reducing the power and extending the time of scanning a single image.
- Voxel – with the changing distance, a voxel value changes as well (see Fig. 4). Voxel size affects the surface determination (different junctions between the air and the material). In case of smaller objects, loss of details occurs (small magnification) as well as a potential error in evaluation of the chosen parameters.

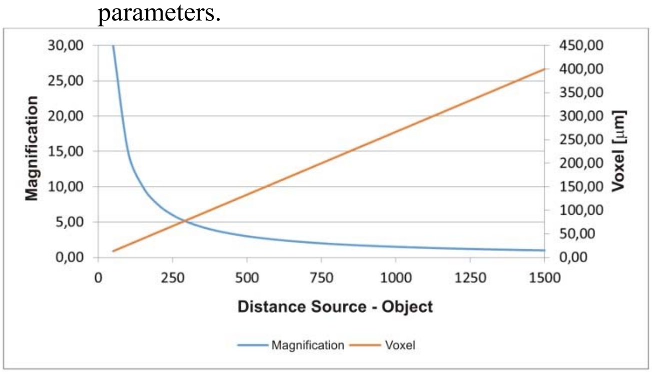

Fig. 4. Magnification and voxel dependency on scanning distace

The objective of the verification is the inter-comparison of the evaluated dimensions L1, L2, L3 at various scanning distances (a distance between a scanned object and the X-ray tube). The distances were chosen so that they cover the maximum extent of the total scanning distance of the machine. In order to identify the impact of the distance, the distance covering only G1, G2 probes was chosen as well, but here only the L1 dimension was evaluated. Individual scans were carried out using the settings listed in Table 3.

The scanning was carried out for four different scanning distances. The Table 3 indicates that the scanning parameters at the distance of 130 mm had to be adjusted, as it was necessary to reduce the spot value (radiation source spot size). At other scanning distances, the same input scanning parameters were adhered to. Change of a voxel size is caused by the change of the distance between the X-ray emitter and a scanned object which cannot be affected. A voxel value can affect the scanning result, as the probe diameter Φ 5 mm for the scanning distance of:

- 130 mm consists of 142 voxels (5000μm/35μm),
- 1200 mm consists of 15 voxels (5000μm/318μm).

Table 3. Parameter of measurements

Scanning	Scanning distance [mm]	Spot [μm]	Voxel [μm]
SN1	130	32	35
SN2	350	64	93
SN3	600	64	160
SN4	1200	64	318

3.1. Surface determination

To evaluate the distances L1, L2, L3, setting for the surface determination must be determined so that they are suitable for all scans. Entire artefact consists of several materials (carbon probe body, ruby or nitride ball). Surface selection is important, but in this case, considering the shape of the used elements (balls), it is not expected to have significant impact on identification of L1, L2, L3 dimensions. In order to evaluate the distance, "Automatic Surface Determination" was selected with an activated option of the "Search distance". With regard to the fact that the balls are made of two different materials, evaluation of distances between the balls required the use of additional two surface settings (manually for the ball material). It means that the impact of the material on the surface determination and on the evaluated dimensions will be considered as well. The impact of the surface determination is minimised by the shapes of elements.

3.2. Coordinate system determination

Evaluation of lengths requires the determination of a coordinate system in which the distances will be evaluated. To create such system, it is first necessary to create required elements which will be used to create the system. In this case, these elements represent the centres of sphere surfaces created on surfaces of individual touching probes. Sphere surfaces were created applying the method of smallest squares (Gauss). By connecting individual centres of spheres, a reference plane is formed (zero for Z); by connecting the centres of spheres G1, G2, a direction vector is created for the coordinate system's orientation, and the G1 sphere represents the beginning of the coordinate system for X and Y axes Fig. 5.

Centres of spheres are created from the maximum surface located within the element's definition. This eliminates, in the maximum possible extent, a shift of the sphere's centre. With less extensive coverage, the impact of the sphere's shape is more significant.

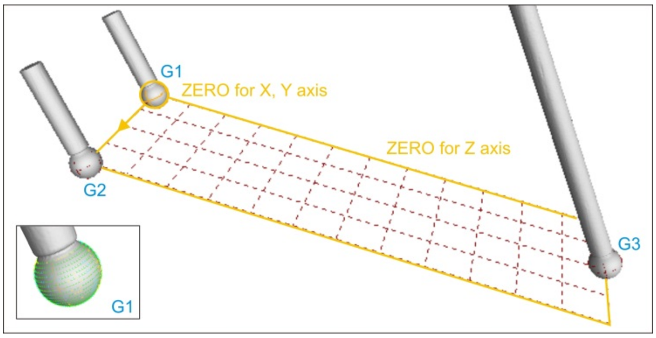

Fig. 5. Coordinate system

4. EVALUATION OF MEASUREMENTS

L1, L2, L3 distances are created as lines connecting the centres of individual balls. With the selected coordinate system it is a simple distance between individual ball centres. For each scanning distance (excluding 130 mm), three surface determinations were used.

For these settings, the L1 – L3 distances were subsequently evaluated. For individual settings and distances, the variation range (VR) was also calculated, which is defined by the difference between the highest and the lowest value of the observed mark [5].

Table 6 shows the values of distances measured for individual settings (distance, surface determination) and the variation range (VR) for individual evaluated distances L1 – L3, whereas the maximum variation range is 0.006 mm. The maximum permissible error MPE_E of the machine is 9+L/50, where L is the distance between two measured points in millimetres. In case of L1 distance, it is

$$MPE_E = 9 + L1_a/50 = 9 + 23{,}75/50 = 9{,}475\mu m \quad (1)$$

where $L1_a$ is the average distance rounded to 2 decimal places (Table 4).

Table 4. Calculated MPE_E

	Evaluated dimensions		
	L1	L2	L3
Average value [mm]	23.75	82.71	83.19
MPE_E [μm]	9.475	10.645	10.664
Minimum value [mm]	23,741	82,699	83,179
Maximum value [mm]	23,759	82,721	83,201

Table 5 shows the values for variation ranges for individual scanning distances; unlike the previous evaluation, they also include the impact of surface determination.

Table 5. Variation range

Scanning distance [mm]	Variation range [mm]		
	L1	L2	L3
130	0.001	-	-
350	0	0.002	0.002
600	0	0.002	0.003
1200	0.002	0.008	0.007

On the basis of the above mentioned facts, it is possible to state that variation ranges for individual dimensions and input conditions did not exceed the MPE_E.

5. CONCLUSION

The measurement results indicate that the evaluated distances L1, L2, L3 show, in measurements at various distances between the artefact and the X-ray tube, the variation ranges smaller than the maximum permissible error of the equipment and a detector. It is an inter-comparison of scans/measurements (evaluation of variation ranges), or a comparison against the referential value (arithmetic mean of the values). On the basis of the results it is possible to state that the designed artefact meets the requirements for the rapid verification of the Carl ZEISS Metrotom 1500 equipment. In case that the distances between individual artefact components are obtained using a more accurate method (e.g. using a coordinate measuring machine), it is possible to carry out the scanning at the determined distance between the object and the X-ray emitter and evaluate the data against these "nominal" data.

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REFERENCES

[1] J. P. Kruth, M. Bartscherb, S. Carmignatoc, R. Schmittd, L. De Chiffree, A. Weckenmannf, *Computed tomography for dimensional metrology*, CIRP Annals - Manufacturing Technology, Volume 60, Issue 2, 2011, Pages 821–842

[2] Metrotom. Visible Metrology

[3] CT Audit project, http://static.gest.unipd.it/~carmignato/ct-audit/

[4] G. Fedorko, V. Molnár, A. Grinčová, M. Dovica, T. Tóth, N. Husáková V. Tabara, M. Kelemen, *Failure analysis of irreversible changes in the construction of rubber-textile conveyor belt damaged by sharp-edge material impact*, Engineering Failure Analysis. Vol. 39 (2014), p. 135-148. - ISSN 1350-6307

[5] J. Majerník, M. Švída, Ž. Majerníková, *Medicínska informatika*, Univerzita Pavla Jozefa Šafárika v Košiciach, Košice, 2010

[6] R. Boris, J. Majernik, K. Pancerz, E. Zaitseva, *Usage of Industrial Computed Tomography for Evaluation of Custom-Made Implants*, Applications of Computational Intelligence in Biomedical Technology, Springer, 2015, Pages 29-45

[7] T. Tóth, A. Végh, M. Dovica, J. Živčák, *Influences of Surface Determination for Measurements Obtained by Industrial Computed Tomography* Applied Mechanics and Materials : VVaPOL 2014 : Conference on Research, Production and Use of Steel Ropes, Conveyors and Hoisting Machines, Volume 683 (2014), 2014, Pages 142-146.

Table 6. Evaluated dimensions

Scanning distance [mm]	Automatic determination			Determination with ruby (G1, G2)			Determination with nitride (G3)		
	L1 [mm]	L2 [mm]	L3 [mm]	L1 [mm]	L2 [mm]	L3 [mm]	L1 [mm]	L2 [mm]	L3 [mm]
130	23.747	-	-	23.746	-	-	-	-	-
350	23.752	82.708	83.189	23.752	82.710	83.191	23.752	82.710	83.191
600	23.751	82.708	83.187	23.751	82.710	83.190	23.751	82.710	83.190
1200	23.752	82.707	83.187	23.750	82.715	83.194	23.750	82.715	83.194
Variation range [mm]	0.005	0.001	0.002	0.006	0.005	0.004	0.002	0.005	0.004