CZASOPISMO TECHNICZNE M
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ
z. 3-M/2008
ISSN 0011-4561
ISSN 1897-6328

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ANALYSIS OF COMPUTER TOMOGRAPH SELECTED PARAMETERS IN TERMS OF SHAPE REPRODUCTION

ANALIZA WYBRANYCH PARAMETRÓW TOMOGRAFU KOMPUTEROWEGO W ASPEKCIE ODWZOROWANIA KSZTAŁTU

A b s t r a c t

Computer tomography is a new discipline of huge development possibilities in industry as well as medicine. CT owes its success to economy. Apparently, it is a necessary tool which allows growing efficiency of manufacture and reducing costs in different branches of industry. In future we can expect falling prices of tomography devices and new possibilities of implementation of CT in new branches of industry. This paper briefly presents the parameters which decide of CT implementation in shape mapping.

Keywords: *computer tomopgraphy, CT, industry application, shape mapping*

S t r e s z c z e n i e

Tomografia komputerowa ma przed sobą ogromne możliwości rozwoju zarówno w zastosowaniu przemysłowym, jak i medycznym. Jest to niezwykle przydatne urządzenie pozwalające na zwiększenie efektywności produkcji oraz zmniejszenie jej kosztów w różnych gałęziach przemysłu. Rozwojowi tomografii komputerowej sprzyjają spadek cen sprzętu elektronicznego i bardzo dynamiczny rozwój branży komputerowej oraz nowe możliwości zastosowań tomografii komputerowej w nowych branżach przemysłu. Artykuł poświęcony jest parametrom TK pozwalającym na zaimplementowanie odwzorowania kształtu badanych obiektów oraz prezentuje kilka z możliwych obszarów jego zastosowań.

Słowa kluczowe: *tomograf komputerowy, TK, odwzorowanie kształtu, przemysł*

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1. Introduction

1.1. Basic information on computer tomography

Computer tomography is a method which allows examining material objects using X-ray radiation. It allows obtaining a 3D or 2D image of the examined object thanks to a series of 1D measurements and the subsequent computer processing of the collected data. In the case of radiography, it is possible to obtain only a 2D grey scale image of a 3D object, projected onto a plane, which results in overlapping of numerous shadows from elements located in the pathway of the radiation beam at various depths. This prevents separation of 3D structures along the radiation propagation vector, based only on the obtained image. The next radiography limitation is linked with the problems related with observing 3D structures characterized with minor differences in radiation absorption coefficients when compared with the ambient material.

Due to such limitations, it is much more convenient to apply computer tomography, which allows estimation of 2D cross sections with arbitrary orientation in space, with the final resolution of approximately 0,5 mm and with the capability to observe structures with the difference in radiation absorption coefficients as low as 0,4%. This means that computer tomography is approximately 5 times more sensitive than classical radiography.

1.2. Evolution of tomographs

The very first tomograph was installed in 1971 and allowed only head examinations. It was the first generation device, employing a single detector, displaced together with a lamp in a traversal and rotational way. The data collection time was estimated at approximately 4,5 minutes. In 1974, Delta type tomographs were deployed, with an increased number of detectors simultaneously analyzing radiation from a number of "pencil" type beams or a single "fan" type beam (second generation tomograph). The data collection time was re-

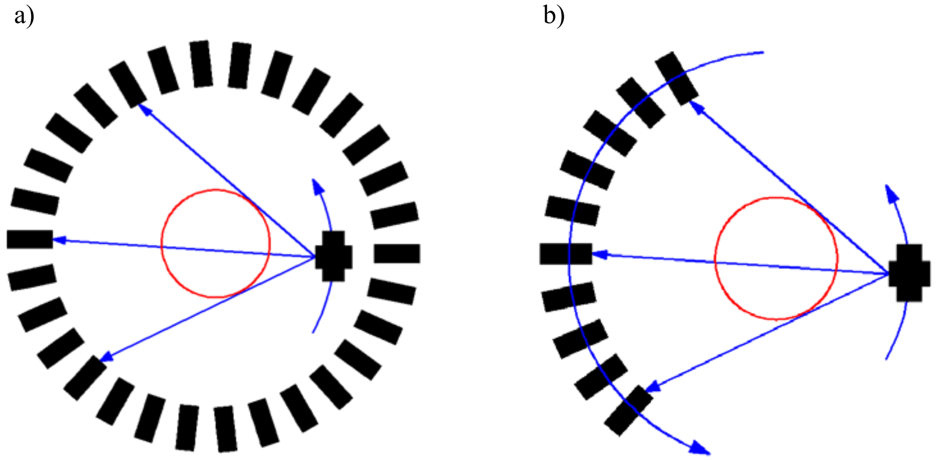

Fig. 1. Diagram of a computer tomograph: a) fourth generation, b) third generation

Rys. 1. Schematy tomografu komputerowego: a) czwartej generacji, b) trzeciej generacji duced to 20 seconds. In the third generation tomographs (see Fig. 1), which were initially deployed in 1976, rotational displacement was employed, which allows for further increase in the number of detectors in such a way that the examination beam covered the whole cross section of a patient. Scintillating detectors were replaced with gas ionization chambers and the data collection time was further reduced to 5 seconds. The fourth generation tomographs (see Fig. 1), had an arch of spinning detectors replaced with a ring of scintillating detectors, which further simplified the mechanics of the device. Such a design evolution was possible thanks to replacement of the initially deployed detectors, in the form of scintillators connected with photomultipliers, with gas filled ionization chambers and then even more efficient scintillating crystals, the radiation from which was collected using photodiodes.

1.3. Image reconstruction

1.3.1. Linear backward projection algorithm

The simplest version of this algorithm assumes a constant sensitivity distribution curve. Additionally, it is assumed that the sensitivity factor is the same for various sensitivity regions. Figure 2 depicts the sensitivity distribution plane for a four electrode system, when the measurement was conducted between the first and the fourth electrode [4].

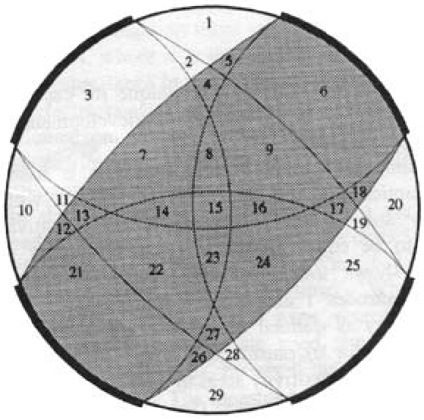

Fig. 2. Sensitivity distribution for a four electrode system,
for a measurement conducted between the first and the fourth electrode

Rys. 2. Rozkład czułości pomiaru w 4-elektrodowym systemie w obszarze
pomiędzy pierwszą i czwartą elektrodą

The sensitivity factor is defined only inside the designated areas in a binary way (1 or 0). By drawing the edges of the sensitivity regions for each possible electrode configuration, it is possible to obtain N regions/pixels. In the case of a four electrode system, there are in total 29 regions/pixels. In order to estimate the grey scale coefficient for pixel k, it is necessary to have all the possible measurements taken, which may influence the information about this particular pixel. This includes therefore all the measurements for which the pixel k is included in the sensitivity region. The normalized sensitivities are then added and divided by the measurement count. Then the k pixel has its grey scale coefficient value $g(k)$ expressed as follows

$$g(k)=\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{C_{ij}^{m}-C_{ij}^{\text{gas}}}{C_{ij}^{\text{oil}}-C_{ij}^{\text{gas}}}\delta_{ij}(k)}{\sum_{i=1}^{n-1}\sum_{j=i+1}^{m}\delta_{ij}(k)}=\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}N_{ij}\delta_{ij}(k)}{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\delta_{ij}(k)}$$

where:

n – electrode count,

δ_{ij} – 1 if the k pixel is located inside the sensitivity region for the given electrode couple (i and j) and 0 otherwise,

C_{ij}^{m} – measured capacity between the given electrode couple (i and j),

N – normalized capacity between the given electrode couple (i and j).

1.3.2. MOR algorithm

MOR (Model Based Reconstruction) defines a way of reconstructing the object based on the initial model. This algorithm attempts therefore to minimize the difference between the measured and estimated capacities by changing the dielectric constant distribution used in the simulated modelThis particular process (dielectric constant distribution) can be described by n parametersThe MOR algorithm defines this particular set of n parameters via simulation and optimization processes. The simulation process (see Fig. 3) is carried out to estimate the capacity as a function of dielectric constant distribution, described with n parameters, and the optimization step is used to minimize the difference between the calculated and measured values.

The MOR algorithm provides in reality much better results when compared with the linear backward projection mechanism. There are no fuzzy edges and borderlines between various substances with different dielectric constants. The reconstructed image differs insignificantly from the real situation.

2. Selected parameters of a computer tomograph

2.1. Radiation attenuation coefficient μ

The image of the examined object is generated based on the value of linear X-ray radiation attenuation coefficient, which is estimated for all particular elements of the examined object. The values of this particular coefficient are given in normalized HU units (*HU – Hounsfield units, CT values, CT numbers*).

Recalculation of the linear radiation attenuation coefficient μ into HU scale is carried out using the following formula

$$HU_{\text{object}}=\frac{\mu_{\text{object}}-\mu_{\text{water}}}{\mu_{\text{water}}}\cdot 1000$$

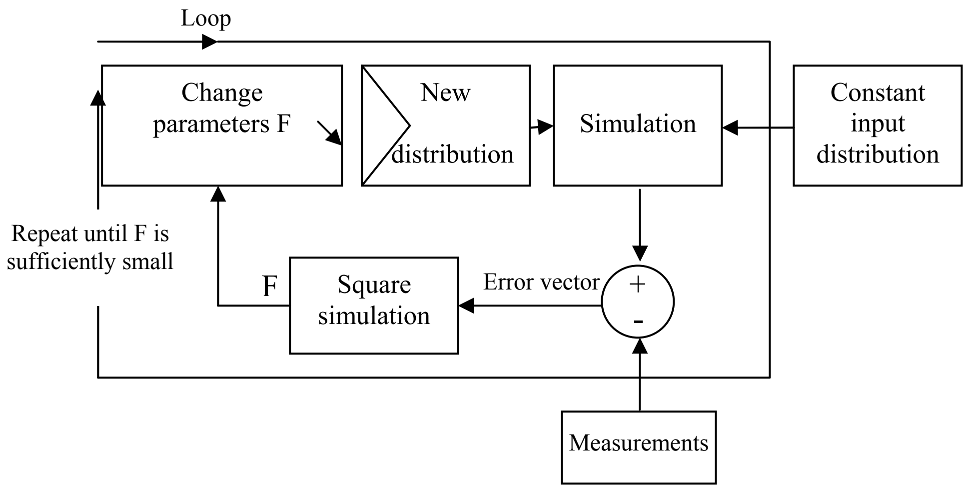

Fig. 3. A block diagram of image reconstruction simulation, using the MOR algorithm

Rys. 3. Schemat symulacji rekonstrukcji obrazu z użyciem algorytmu MOR

By assigning appropriate grey scale levels to HU coefficients, it is possible to obtain a tomographic image.

In accordance with the definition, water is assigned HU = 0. For any material and selection of imaging parameters, the HU value averaged over the total image area should be a constant value. Minor HU variations over time do not impact the quality of the examined image.

It is worth noting, though, that the HU values exhibit certain random variation between individual data points. It is caused by the construction limitation (limited number and efficiency of detectors, imperfect reconstruction algorithms) and quantum nature of emission processes and interaction of X-ray radiation photons and matter [3]. This particular variation is thus defined as noise level in the system.

2.2. Noise

Noise in this particular system is defined as a standard deviation for the HU value in the selected region of a uniform phantom. An increase in the noise level is caused by the errors in the operation or exploitation of tomograph elements (lamps, detectors), which results in reduced visibility of elements with lower contrast. There are ways to limit the noise level, which is typically employed by increasing the radiation dosage. This may however result in erroneous operation of beam collimators, responsible for selection of the layer thickness.

2.3. Spatial image resolution

The ability to distinguish point objects located close to each other is typically termed as spatial imaging resolution. It is limited by construction parameters of the tomograph (size of the lamp's focal point, number and size of detectors etc.) and selection of the examination parameters (number of subsequent projections, reconstruction algorithm etc.).

An additional limitation originates from the digital image processing technique itself, where the size of the image element (pixel) is directly related with the reconstruction matrix size as well as the size of the reconstructed image. Image resolution deterioration may be caused by a number of operational errors of the device or wear of the lamp's focal point, but always results in deterioration of the diagnostic quality of the final image [3].

2.4. Modulation transfer function

MTF (*Modulation Transfer Function*) indirectly determines the ability of the given tomograph to reproduce specific spatial frequencies (see Fig. 4). This particular parameter is calculated as a ratio of the image modulation depth and the object modulation depth for the given spatial frequency, following the formula

$$MTF(f) = \frac{(A_{\max} - A_{\min})/(A_{\max} + A_{\min})}{(A_{0\max} - A_{0\min})/(A_{0\max} + A_{0\min})}$$

where:

$A_{\max}$, $A_{\min}$ – maximum and minimum HU values for the given object,

$A_{0\max}$, $A_{0\min}$ – maximum and minimum values of the linear radiation attenuation coefficient in the imaged object.

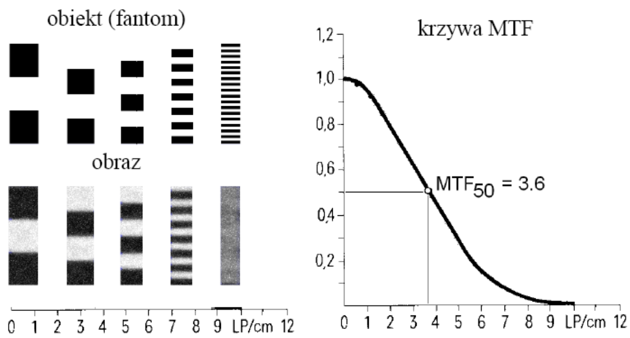

Fig. 4. The MTF function describes the way objects of various sizes are spread in the image

Rys. 4. Funkcja MTF opisuje, w jaki sposób obiekty o różnych rozmiarach są rozmywane w obrazie

3. Analysis of tomograph parameters and its application in industry

The aforementioned parameters are most vital when it comes to reproduction of the shape of the examined objects. Taking into account a manufacturing process for a complex element, the testing of which is time consuming, it is beneficial to employ a computer tomograph to examine its geometric parameters right after the production phase. Depending on the material used to manufacture the particular object (e.g. metals), various radiation attenuation coefficient values will be present in the final product, thanks to which the reconstructed image will be sharper and which will allow for more precise reproduction of its shape, as depicted in Fig. 5.

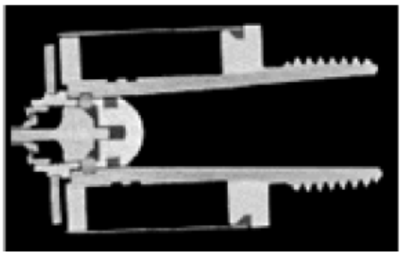

Fig. 5. An image of a certain element obtained with
the aid of computer tomography

Rys. 5. Obraz elementu uzyskany za pomocą tomografii komputerowej

Consequently, the modulation function will assure that with more differentiated HU coefficient values the obtained image will not be blurry, which allows for rapid examination of the measured dimensions. It is also obvious that CT can be employed in manufacturing various products for continuous and rapid production quality control. It must be emphasised, though, that current industrial class computer tomographs are not the cheapest available measurement devices and require additional professional CAD software.

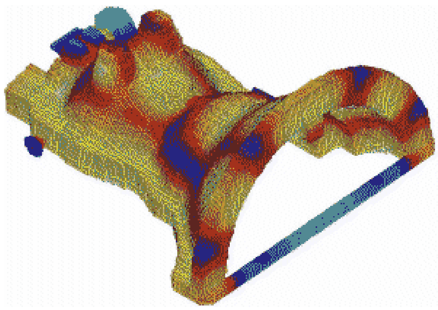

Fig. 6. Cast image when compared with the designed model, with indication
of production process distortions and errors

Rys. 6. Obraz odlewu w porównaniu z jego zaprojektowanym modelem,
na którym uwidocznione zostały odchyłki powstałe w procesie produkcyjnym

As an example, let us consider the examined cast (see Fig. 6) which was analysed using computer tomography and its complex surface curves do not allow for rapid analysis of the shape distortions occurring in the production process. Thanks to computer tomography, the obtained image can be rapidly compared with the project and thus it is possible to easily confirm whether the production errors lie within the required tolerance limits.

3.1. A block diagram of an industrial type computer tomograph

The data collected with the detector is subject to appropriate computer processing, which results in the reconstruction of the image of the examined object. It takes advantage of various mathematical procedures (e.g. such algorithms as: Radon, backward projection, convolution etc.).

An example of a measurement post providing such functionality is depicted in Fig. 7.

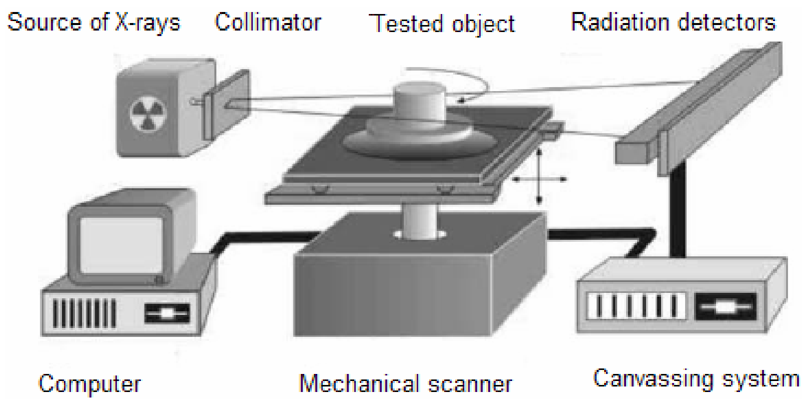

Fig. 7. Diagram of an industrial type computer tomograph [2]

Rys. 7. Schemat przemysłowego tomografu komputerowego [2]

Object control using X-ray computer tomography is a very powerful analysis tool applied todetection of anomalies, characterizing devices and materials, analysis of defects and failures, measurement of dimensions and reverse engineering.

Without any significant problems, X-ray computer tomography can be applied to production of missing or non-existent documentation and manufacturing components for various types of devices, using, for instance, rapid prototyping techniques.

The need of application of X-ray computer tomography to aid the production processes further emphasises its technical and economic value. It can be used for much faster control and supervision of complex elements, which could take several weeks should regular methods be applied – now it can be cut down to a few days only. The photographs below (see Fig. 8) depict the cast of some element and its resulting cross section.

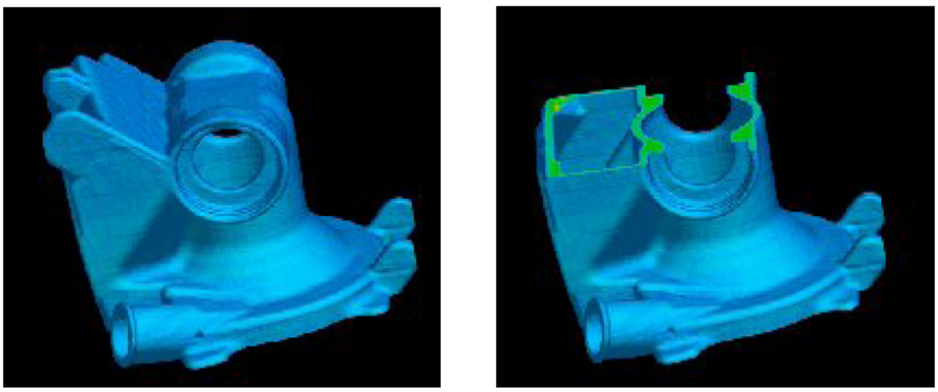

Fig. 8. A photograph of a pump cast and its cross section

Rys. 8. Fotografia odlewu pompy i jej przekrój

References

[1] http://fiz.coi.waw.pl/w.skrzynski/ct.html.

[2] Senczyk D., Moryksiewicz S., *Przemysłowa rentgenowska tomografia komputerowa*, Badania Nieniszczące 3, 2006.

[3] Skrzyński W., *Testy kontrolne aparatów rentgenowskiej tomografii komputerowej,* Szkolenie dla techników elektroradiologii, Oddział Warszawski STE PLTR, Warszawa, 18 listopada 2006.

[4] Cierniak R., *Tomografia komputerowa: budowa urządzeń CT: algorytmy rekonstrukcyjne*, EXIT, Warszawa 2005.