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PRAGUE CENTER OF INDUSTRIAL TOMOGRAPHY: RESEARCH AND APPLICATIONS IN NDT

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Abstract

X-ray computed tomography (CT) has achieved its expansion not only in medicine, but recently also in the field of NDT, where CT occupies a significance position due to state-of-the-art technologies based on the interconnection of physical and mathematical principles in conjunction with informatics. The Prague Center of Industrial Tomography (PCIT) at the Czech Technical University (CTU) in Prague is developing its activity in term of physical aspects such as X-ray interactions with matter, the physics of detection, X-ray detectors and relevant novel methodologies. Considerable effort is spent on suggestion and implementation of arrangements that will have a positive influence above all on the resolution determining the quality of acquired data and the quality of imaging. For instance, the differential tomography based on spectral resolution.
The indivisible part of research is to acquaint students with a broad issue whether within the lectures or eventually through an involvement of the active students in research projects.
Since the Center is equipped with two industrial tomographs of a VT series, VT 50 and VT 400, the industrial applications in NDT or in natural science find an extensive usage by these devices.
CT as NDT method has quite a number of advantages. The ability to reveal internal structure together with high resolution, high sensitivity and availability of 3D model output qualified this method for broader utilization also in industry despite higher investment and operation costs.
Among others, our intention is to inform about further developments and research activities in PCIT with an expected use in industrial applications.

Key words: X-ray computed tomography, X-ray detectors, X-ray interaction with matter

1. INTRODUCTION

More than hundred years elapsed since the discovery of X-rays and their utilization for nondestructive testing is already well known. Because of their penetrating nature, the varying abilities of materials to attenuate them and the capability to record their intensity on film or other detectors, X-rays are the ideal means to determine the inner composition or structure of an object. In radiography, image is produced so that represents the superimposed structure between an X-ray source and a detector. To eliminate the superposition, the computed tomography (CT) was developed.

The principle of computed tomography consists in measurement of attenuated X-rays passed through a tested object along the set of defined paths (multiple X-ray transmission projections) followed by the reconstruction of acquired dataset with the aid of mathematical reconstruction algorithms. The result is the distribution of attenuation coefficient $\mu(x, y)$ for individual pixels in each cross-section plane.

For simplicity, one of the classical tomograph configurations is considered where the tested object is moved in one direction and radiated by the thin beam of rays. Then the object is rotated and the scanning process is repeated.

This method is well developed and widely applied in both the medical and industrial inspection fields.

X-ray CT as a non-destructive testing method has achieved a high progression in the last decade. The considerable efforts have concerned the installation of these devices not only in research laboratories, but also directly in industrial companies.

The Prague Center of Industrial Tomography at CTU has become the object of the link between science and industry. The most of activities are aimed at the enhancement of image processing through the study of X-ray interactions with matter and the physics of detection.

2. RESEARCH

The progress in research is being expected to be intensified with the upcoming new equipments. Till this time the effort was aimed to the conventional method of CT based on transmission effect. The center is equipped with two industrial CT tomographs of the VT-series: VT-400 and VT-50. Each of the models has its own application fields. The VT-400 model (420 kV/2 mA) is designed for testing large-size specimens up to 400 mm in diameter. The VT-50 (120 kV/50 μA microfocus tube) model can be used for analysis of the microstructure of small samples up to 20 mm in diameter.

Considering the fact that the linear attenuation coefficient is a function of the bulk density, ρ, effective atomic number Z, and energy E, the knowledge of element composition is highly demanded. The Faculty of Nuclear Sciences and Physical Engineering at CTU also disposes with the equipment for elemental composition analysis. Namely, for this analysis of the investigated object, the energy dispersive X-ray fluorescence analysis (XRFA) is successfully used. X-ray fluorescence (XRF), as based on photon excitation of the electron shells of atoms and subsequent qualitative and quantitative spectrometry of the emitted characteristic X-rays, gives data about elemental composition of the sample. XRFA at the faculty is carried out with a miniaturized X-ray tube. The tube employs a Mo anode and can operate with a maximum current of 0,1 mA at a maximum voltage of 30 kV. The detection module consists of the AMPTEK Si-PIN detector, cooled by a 2-stage thermoelectric cooler and sealed with a Be window [1].

The dependence of the linear attenuation coefficient on the energy of X-rays can be used for setting up the most appropriate energy ranges for best contrast imaging of various elements. Further, dual energy X-ray method, based on combining two images acquired at two distinct energies, could be taken into account. Dual energy X-ray technique allows obtaining both density and atomic number at low energy and high energy measures, and thus providing information about material composition, and improving image contrast. Various methods of spectrum purification or filtration are currently studied. There is still enough space for research and improvements here.

Beside the transmitted beam, other beams resulting from X-ray interactions with matter can be used for detection. Both incoherent (Compton) and coherent (Rayleigh) scatterings are still rather rare X-ray based imaging method revealing structural information. Some experiments aimed to study possibilities and limitations of Compton scattering are currently ongoing at PCIT. In the first series of experiments, the pinhole camera combined with various imaging detectors under study is used. Generally speaking, the unconventional methods mentioned above and differential tomography or radiography based on dual energy present the trend to which the research and development in our laboratory should be more broadly focused in the following period. Until now the information about objects was derived entirely from the transmitted beams of radiation.

3. APPLICATIONS OF X-RAY CT TOMOGRAPHY

3.1 APPLICATIONS IN INDUSTRY

Industrial X-ray computed tomography permits to make both nondestructive qualitative and quantitative evaluation of complex internal structure of the most important parts of modern machinery and electronics, as well as material itself.

The result of CT investigation is being visualized as layer-by-layer images with identification and quantitative estimation of defects such as geometric deflections, different densities, pores, cracks, inclusions etc. Computed tomography exceeds other non-destructive evaluation methods by two orders in sensitivity.

Computed tomographs are efficient tools in working out technology, diagnostics and certification of products e.g. in airspace industry (nozzles, thermal protection, binder joints …), important aircraft assemblies and units (turbine blades, vanes …), complicated car industry products (heads of cylinder block, casting of light alloys, pistons, ceramic units …).

As an example, in Figure 1 it is illustrated the cross section through the periscope, the composition of all slices represents a 3D model enabling the reverse reconstruction of this object.

Figure 1. Part of periscope – 2D and 3D model

Considering the fact of an expansion of automotive industry there is a growing demand for non-destructive porosity assessment. The previous destructive metallographic method is gradually being replaced by nondestructively acquired images - tomograms. Both examples are illustrated in Figure 2. There are several approaches to set the quantity of pores in medium. The simplest methods are based on the adjustment the threshold value for the air/material interface. Apparently it includes the subjective intervention to assessment. Hence our aim is to avoid these human errors and to set up generally true method.

At present the porosity distribution method calculated against CT number is in research studies. The porosity is calculated directly from the CT numbers without using segmentation techniques and without using any user-defined parameters. From a novel distribution which can indicate the properties of the studied materials, the minimum of the curve gives the value of the estimated porosity.

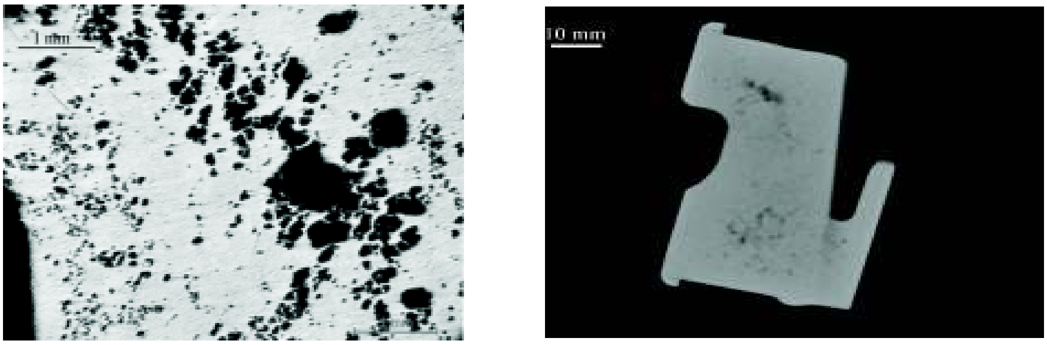

Figure 2. Porosity in zoomed metallographical pattern and cross section
of the whole object by means of CT

3.2 APPLICATIONS IN NATURAL SCIENCES

The Prague Center of Industrial X-ray Tomography (PCIT) has broadened its activity towards the applications in natural sciences. The cooperation has been started up between the Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering and the National Museum in Prague. The collection funds of the National Museum represent several million items of material evidence about the inanimate and living nature and about the man and his activities in worldwide scale.
The exhibits in mineralogy, paleontology, zoology, anthropology, archaeology have become the subject for the research and development. The digital character of a CT dataset makes possible to visualize and animate features hidden from external view. Thus the structure and internal parts of exhibits are revealed and the determination of precise forms and dimensions has achieved the promotion for the latest scientific investigations.
From Department of paleontology, various rare exhibits were examined. One of them is a 90 million-year-old (age of Late Cretaceous) fossilized vertebra of a marine reptile. Using CT and advanced computer data processing, fossilized vertebra was virtually extracted from the surrounding rock (Figure 3, left). Furthermore, the nature of skulls makes them ideal candidate for research within the industrial tomograph. Namely, the skull of a bear from the genus Ursus found at the age of quaternary in Rumania (Figure 3, right).

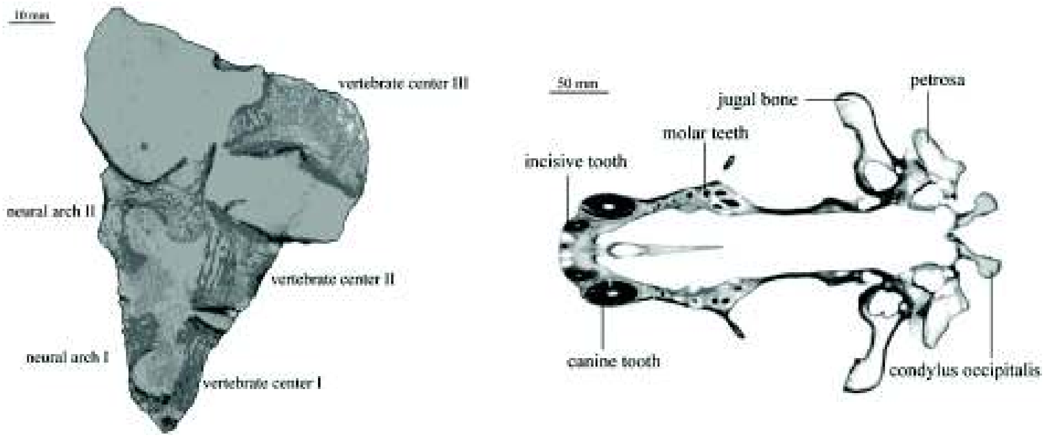

Figure 3: Fossilized vertebra reptile and palatine plane of a bear skull

4. CONCLUSION

The purpose of this paper is primarily to inform about the recent activities in research and the scope of applications for many industrial areas and educational institutions.
Research and development in digital radiography and tomography is expecting to reach a greater expansion in the following period. In this way, we should act as intermediary that conducts development for achievement of challenging requirements assigned by both commercial and non-profit subjects. The planned progress in our laboratory calls for the high level of personnel and equipment quality, which is intended for promotion of the latest scientific achievements in industry and science. Therefore the aim is to integrate more students through incentive projects that will evidently raise the signification of joint centre to higher reputation and competitive strength.

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