Spectral microtomography using the MARS-CT

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Introduction

The MARS microtomograph (MARS-CT) is an innovative microtomograph developed by MARS Bioimaging Ltd. (New Zealand). It incorporates the Medipix detector chip, a new generation X-ray detector. The Medipix is a family of a hybrid pixel detector readout chip designed by an international Medipix Collaboration together with CERN and EUDET. The hybrid (this means that a semiconductor sensor layer of silicon or high-Z material is bonded on to an electronics layer) pixel detector technology was initially developed for particle physics detectors, but the Medipix chip has shown that the technology is also good for X-ray imaging and spectroscopy. Unlike CCD detectors, which operate exclusively on an integral basis, the Medipix type detector allows for single photon counting, and obtaining information about the incident radiation's spectrum. Furthermore, its readout system consists of an independent circuit for each single pixel, rendering it extremely fast. Each chip has 65536 pixels. Every pixel accurately counts the number of photons that reach it within specified energy bands. Black and white CT cannot distinguish different density tissue as they absorb similar amounts of photons. The MARS-CT advances this as body tissue of similar density interacts differently with certain energies. The Medipix chip can detect these

Fig 1: General view of the MARS microtomograph located at the Laboratory of Nuclear Problems of JINR

different interactions. In addition the energy of a photon can change based on interactions with the electron shells of the atoms in the body tissues it encounters. These effects mean that information about both the density and the atomic make-up of a tissue can be imaged and can be assigned to colours on an image. The MARS-CT which contains the gallium arsenide Medipix detector made in Dubna has been purchased by JINR and installed at the Laboratory of Nuclear Problems in September 2013 (Fig. 1).

The MARS-CT

The MARS microtomograph consists of the microfocus X-ray source and a MARS camera based on the Medipix detector, both mounted at the rotating gantry (Fig. 2). The gantry is surrounded by the lead shield so that the setup can be operated safely. The scan procedure is fully automatic and is controlled by the computer. The sample is placed on the rotation axis of the gantry and stays motionless while several hundreds of projections are typically taken during each scan. The projections are later used to reconstruct tomographic slices (Fig. 3). The MARS-CT allows to perform both cone beam circular scans and helical scans of lengthy samples. The size of a sample may be up to the diameter of 10 cm and up to the length of 30 cm. The spatial resolution of ~30 μm is currently achieved.

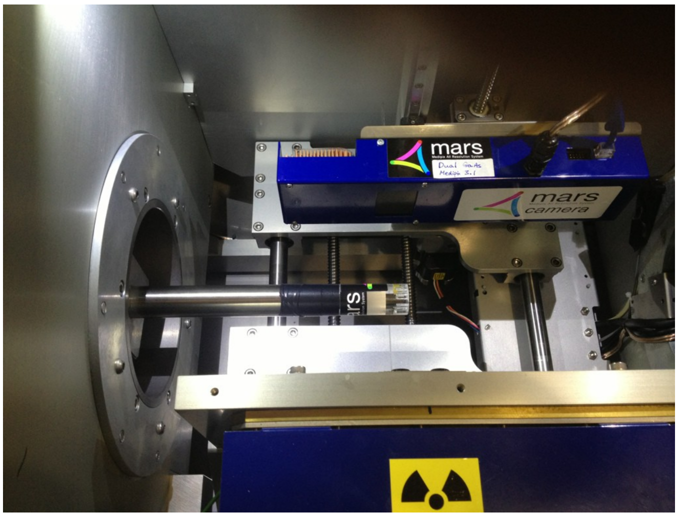

Fig 2: Gantry of the MARS-CT with the X-ray source and the MARS camera and with a sample placed in between.

Fig 3: Image of the rock sample reconstructed at the MARS-CT at JINR (diameter of the sample is about 1 cm.)

Possible applications

The key feature of the MARS-CT is the ability to measure the energy of X-rays coming to the detector. Being combined with the computed tomography it opens the way to determine the element composition in each voxel by measuring the energy dependence of the X-ray absorption coefficent. At most x-ray energies, the absorption coefficient is a smooth function of energy, with a value that depends on the sample density, the atomic number, atomic mass, and the X-ray energy. When the incident x-ray has an energy equal to that of the binding energy of a core-level electron, there is a sharp rise of absorption, called as absorption edge. The energy of the absorption edge is individual for each element, so comparing the images taken in the narrow energy bands below and above the absorption edge of the given element permits to identify the voxels containing atoms of this element. This new capability may lead to the development of new innovative approaches in the biomedical research (tissue identification, new X-ray contrast media in diagnostics, study of drug delivery etc) and in the geophysical studies (ore composition, oil core permeatability etc.)

General research program

Students will learn the following topics:

1. Basic principles of computed tomography
2. Design and operation of the MARS microtomograph
3. Principles and operation of a single photon counting X-ray imaging detector
4. Practical skills of making scans using the MARS tomograph and image processing
5. Basics of spectral tomography.

A good knowledge of C++ and/or Python programming language is very welcome.

References

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4. Tyazhev A.V. GaAs radiation imaging detectors with an active layer thickness up to 1mm. Nucl. Instrum. and Meth. A509 (2003) 34–39
5. Kleinknecht K. Detectors for Particle Radiation. Cambridge University Press; 2 edition, 1999