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New design for the ANTARES-II facility for neutron imaging at FRM II

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ABSTRACT

The advanced neutron tomography and radiography experimental system (ANTARES) facility for neutron imaging is successfully operating at the FRM II reactor of Technische Universität München. In 2009, a redistribution of beam positions at FRM II will require a rebuilding of ANTARES at a different position. In May 2006, the DIDO reactor FRJ-2 at the research center in Jülich has been permanently shut down. The Jülich Center for Neutron Scattering has been founded, and 8 instruments are currently being transferred to FRM II in Munich, where a new experimental hall has been built at the east side of FRM II. The neutron beam SR4b currently hosting ANTARES is the only beam with a cold spectrum that can be extended from the experimental hall of FRM II to the new east hall. ANTARES will have to move to the second channel (SR4a) of the beam tube SR4. Due to the different geometry in relation to the reactor walls, a complete rebuilding of ANTARES is required, including a new shielding concept with lighter materials to meet the restrictions of the permitted floor load together with the new beam line SR4b to the east hall. The complete reconstruction allows the incorporation of several improvements.

1. Introduction

The neutron imaging facility advanced neutron tomography and radiography experimental system (ANTARES) allows users to perform different kinds of measurements and experiments. Radiography, tomography, phase contrast radiography and tomography, dynamic radiography, energy-dependent measurements, high-resolution radiography and tomography, measurements with polarized neutrons, X-ray radiography and tomography, gamma radiography, and auto-radiography.

In the design of the new facility, it is necessary to keep this flexibility; furthermore, the objective is also to obtain higher resolution images, shorter exposure time and a very low background.

A detailed description of the ANTARES-II facility is given and the devices, components, and assemblies we want to use to reach our aims.

2. Neutron beam

In the biological shield of the FRM II, 12 beam tubes are tangentially arranged around the core with the nose close to the maximum flux of thermal neutrons or one of the secondary sources. One of them is SR4. It is designed to deliver two neutron beams with a cross-section of $120\,\mathrm{mm} \times 120\,\mathrm{mm}$; the nose looks directly onto the cold source.

A cold neutron spectrum peaked around 5 meV is supplied by a liquid D_2 moderator (20 l sphere with re-entrant hole, at a temperature of about 25 K). The average (integral) neutron flux density in the cold source is approximately $3 \times 10^{14}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (at a nominal reactor power of 20 MW; perturbed by flux depression), resulting in a cold neutron flux density of $9.1 \times 10^{13}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ [1].

The new facility ANTARES II will be installed at the SR4a channel. The channel SR4b will be used to fit a cold neutron guide to the new experimental hall situated at the east side of the reactor.

Both channels have a common drum shutter situated inside of the biological shield.

The first point to consider in the definition of the neutron beam is to transmit as many cold neutrons as possible from the beam tube's nose to the sample to be irradiated in order to maximize the neutron statistics on the detector. Therefore, the whole channel cross-section $120\,\mathrm{mm} \times 120\,\mathrm{mm}$ will be kept open as option for measurements where high flux is required but with relatively low L/D ratio ($L/D = 166$), for example in dynamic measurements [2].

The next option is a small aperture as close as possible to the neutron source to obtain a large fully illuminated area.

The best possible position is 4.5 m from the cold source and the aperture is actually a 1 m long block made of low cobalt steel with

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a conical channel and a cadmium ring in the smallest opening. This configuration allows a fully illuminated area of 400 mm × 400 mm, $L/D = 3000$ at 20 m from the cold source and a fully illuminated area of 140 mm × 140 mm, $L/D = 1500$ at 10 m from the cold source.

In order to obtain more options for the beam geometry definition, a drum collimator selector will be integrated into the first shielding block. Within the selector, it is possible to fit six collimators with a length of 800 mm. In the first two positions, collimators for $L/D = 800$ and 400 are planned; in the third position, one unit with a very narrow aperture (diameter of the aperture in order of 1 mm) for phase contrast measurements.

The fourth position remains fully open with 120 mm × 120 mm. The fifth and sixth are spare positions depending on the future development.

An additional option to define the beam geometry is a coded mask positioned directly in the entrance of the first shielding block. It is a cadmium element with numerous pinholes in a non-redundant array pattern. They transmit more neutrons than only one aperture, which reduces the phase contrast exposure time. A consecutive deconvolution of the image must be done by computer [3].

3. External vertical beam shutter

Outside of the biological shield an external vertical beam shutter will be mounted. This will be the main shutter for ANTARES II as the preceding drum shutter cannot be closed when the beam SR4b is in use. The vertical displacement is uncomplicated and allows a simple fail-safe mechanism in case of emergency or power failure [4] (Fig. 1).

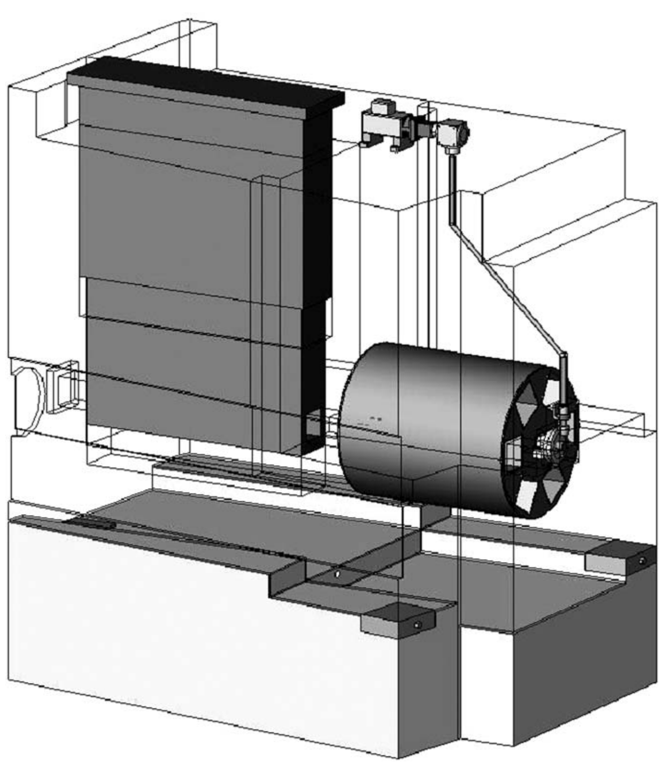

Fig. 1. First shielding element with external vertical shutter and drum collimator selector.

4. Beam formation area

The beam formation area is located in the first chamber directly behind the first shielding element. Here, a group of instruments will be mounted which modify the properties of the neutron beam depending on the requirements of the measurements, includes the following.

Fast shutter: Closes the cold neutron beam between individual images of a tomography and reduces the activation of the sample.

Multi-filter [5]: This is a device for positioning different single crystals in the neutron beam. Sapphire will be used as filter for epithermal neutrons, bismuth and lead as filter for gamma radiation. With a beryllium filter, the contrast in neutron radiographies can be increased for combinations of certain materials, as only cold neutrons ($\lambda > 4$ Å) are transmitted.

Aperture wheel for phase contrast: A remote controlled wheel for the positioning of cadmium sheets with eight different slotted and circular orifices from 1 to 7 mm in diameter.

Double crystal monochromator: Allows energy-dependent measurements between 2.7 und 6.5 Å.

5. Neutron periscope assembly

The first prototypes of neutron periscopes have been designed, built and tested by the ANTARES team at FRM II [6].

Basically, such a periscope consists of a box with two parallel super mirrors. The first mirror reflects neutrons out of the direct line of sight and the second mirror brings the reflected neutrons in a direction parallel to the entrance direction.

The fast and epithermal neutrons and gamma radiation are absorbed in a beam stopper consisting of a block of borated polyethylene and lead. When the periscope is positioned near to the neutron source it is possible to obtain a clean cold neutron beam, and the noise in the measurements is significantly reduced. One disadvantage is the limitation of the field of view due to the very flat reflection angle (1–1.3°) depending of the value m of the mirror. Nevertheless, with a device of about 3 m length the illuminated field has a width of 100 mm and a height of 50 mm, which is acceptable for most general applications (Fig. 2).

6. Flight tube

The new facility ANTARES II will have modular flight tubes adapted to the dimension and position of the neutron beam. The penumbra will be partially absorbed in the partition walls (W1, W2) allowing to reduce the diameter of the flight tubes.

The flight tubes are not evacuated. In order to avoid potentially dangerous situations and to reduce the thickness of the entrance and exit windows, the tubes will be filled with He. Because there is no difference in pressure between He inside the flight tubes and the atmosphere outside, the tubes' windows can be made of very thin aluminum sheets (Figs. 3 and 4).

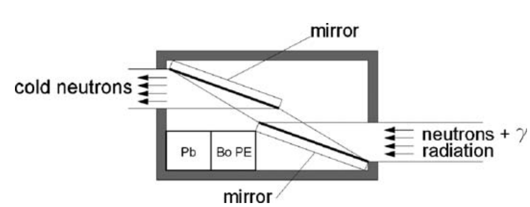

Fig. 2. Schematic drawing of neutron periscope.