Limited View Tomography of Wood with Fast and Thermal Neutrons

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Abstract. Neutrons are absorbed particularly by hydrogen containing materials so they can be used as a tool for visualising heterogeneous density distributions of organic materials. Penetration limits are set by the layer thicknesses and the neutron energies applied. In case of specimens with a flat shape the situation may be encountered that the object only could be penetrated in selected directions. In addition, the overall size may exceed the beam diameter and thus the viewing window if a certain region of interest should be studied by tomography without destroying the integrity of the specimen.

This study shows the capabilities and limits of thermal and fast neutrons to investigate flat wooden specimens such as boards and girders by neutron tomography under such circumstances. Taking projections was impaired either by the limits of penetrability or by the total size of the object. As a consequence, projections were included for reconstruction only from a limited angular range of 90°. It could be shown that an approach based on the slice theorem was capable to visualise structural features along the beam directions while simply omitting the perpendicular ones without causing additional artefacts.

Small samples with a thickness of up to 2 cm but several times broader could be studied with the ANTARES facility of the FRM II neutron source in Garching providing thermal neutrons while larger objects required a beam of higher energy as available in the NECTAR facility of the same institution. The fast (fission) neutrons (1.5 – 2 MeV) of this site allowed investigating an area of interest inside a girder with a cross section of 23.5 x 49 cm^2. Internal features such as inclusions could be detected as well as a heterogeneous density distribution in glue layers.

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Introduction

Neutron radiography was chosen to visualise glue layers in wooden boards or girders because of the absorption properties in hydrogen containing materials [1]. It has been shown that wooden layer of up to 30 cm could be penetrated by fast neutrons [2]. It is a common experience that this distance cannot be reached by far with thermal neutrons; the exact value remains to be determined. In any case, the permeability limits for neutrons in some selected directions constitute already one obstacle for tomography. The other one may be simply caused by the size of the specimen itself exceeding the diameter of the beam line in some directions. A solution to this problem is provided here by a limited angle tomography.

Methods

1.1 Reconstruction

The reconstruction algorithm applied was validated with a digital image consisting of artificial features. Due to the high L/D values of both neutron radiography facilities mentioned below it was reasonable to assume a parallel beam geometry so the projection images could be used directly for a layer by layer reconstruction based on the slice theorem [3]. In contrast to a filtered back-projection, this approach principally is less prone to artefacts in case of a limited angle tomography due to missing projections, if at all. Artificial projections from an image of a grey rectangle crossed with black and white lines as well as containing a black and a white dot was taken to proof this fact. The size of the experimental images for reconstruction was 1024 x 1024 pixels (512 x 512 for the theoretical model), the step size 1° or less from projection to projection.

1.2 Thermal Neutrons

Projections for a tomography of small specimens were collected in the ANTARES facility of the Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) in Garching with 2.6 x 10^7 neutrons / cm^2 s and an L/D ratio of 400. The image detector consisted of a fluoroscope consisting of a ZnS(Au,Ag) +LiF scintillation screen and an Andor DW 436 cooled CCD camera. A step wedge of 4 cm length with four consecutive steps of 0.5 cm ranging from 0.5 to 2 cm was taken for probing the maximum penetration depth of the neutron beam. The specimen studied is shown in Figure **1a**.

a **b** **c**

Figure 1. Specimens for tomography:
a) board 16 x 40 x 2 cm3 for thermal neutrons, **b)** girder 49 x 23.5 x 100 cm3 for fast neutrons, **c)** beam size of fast neutrons and rotation axis of the specimen (girder in b).

1.3 Fast Neutrons

Larger specimens requiring fast neutrons for penetration were investigated in the NECTAR facility of the FRM II which has a neutron flux of 4.9 x 10^6 / cm^2 s and an L/D of ~ 230 [4]. The image detector consisted of a fluoroscope with a PP converter and an electrically cooled Andor DV434-BV CCD-camera with 1024 x 1024 pixels. The interrogated specimen is shown in Figure **1b**.

Results

2.1 Theoretical Model

Projections were generated from an image of a structured rectangle resembling a cross section of a board. They were aligned in a sinogram as shown in Figure **2**. The black lines on the left within the grey rectangle in the panel **2a** appear as troughs while the white ones on the right as peaks within the sinogram (panel **2b**). The spherical features layered centrally, i.e. the white and black dot, turned into patterns running through the whole range of 180°, i.e. from bottom to top. It became quite obvious that the patterns of the sinogram related to the crossing lines are located within the range marked in red covering projections within a 90° section only. It therefore seemed reasonable to take the 90° section only for visualising those features. This has been verified by reconstructing an image including the inner 90° section only as compared to a full angular tomography (see Figure **2**, panels **c** and **d**). Including just the 90° range the bottom and the top of the rectangle running more or less perpendicularly to the beam directions were correctly missing.

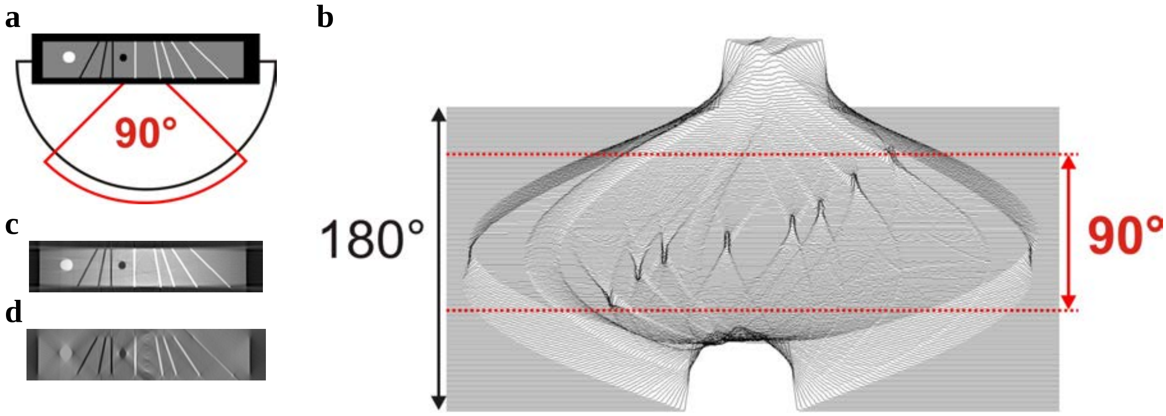

Figure 2. Full and limited angle tomography of an artificially constructed sample
a) Rectangle with patterns resembling the cross section of a board with 180° (black) and 90° (red) viewing angles, **b)** sinogram of all projections, inner section of 90° marked in red, **c)** 180° reconstruction, **d)** 90° reconstruction comprising the marked selection.

2.2 Thermal Neutrons

First of all, the limits of penetration were probed in a step wedge as shown in Figure **3** representing the cross section of a tomographic reconstruction covering all angles between 0° and 180°. The annual ring patterns are clearly visible in the upper two steps, i.e. in a penetration depth of up to 2 cm. Thereafter they are fading out. The edges between the steps even demonstrate that this layer thickness already exhibits a critical limit. The one on the top is only faintly visible, i.e. some critical structures could only being seen within 1.5 cm.

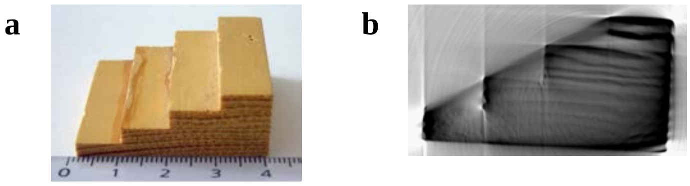

Figure 3. Step wedge for probing the penetration depth of thermal neutrons,
a) specimen, **b)** central cross section (180° reconstruction).

The board investigated by tomography as shown in Figure **1a** had a thickness reaching the limits of the method so it appeared conceivable to take a 90° section only for reconstruction as presented in Figure **2a**. As a result, the glue layer in the centre was clearly visible in central cross sections viewing from the top and through the plane (Figure **4**) but omitting the bottom and top surface of the board. Marginally, a few annual rings (left) and knots could also being detected. Thus far this result was consistent with the theoretical model shown above (Figure **2d**). The further panels of Figure **4** demonstrate longitudinal sections through the board, one parallel to the plane and another one directly through the glue layer perpendicular to the broadside of the board (lateral view). The section directly through the layer (maximum absorption of 10 layers) showed a heterogeneous density distribution of the glue which was obviously penetrated preferentially into the annual rings. Principally, it was even possible to further restrict the selected section down to 60° without loosing the characteristic features of the glue layer [5].

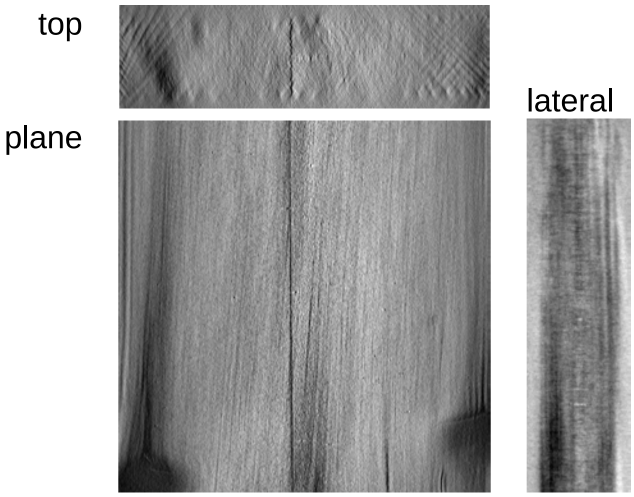

Figure 4: Thermal neutron limited angle tomography (covering 90°): view on sections through the board from top, the plane and the side (glue layer).

2.3 Fast Neutrons

The specimen shown above in Figure **1b** was of a size that only could be interrogated with fast neutrons. Furthermore, the cross section of the beam line allowed only investigating a certain area of interest within the object without shifted scanning as demonstrated in Figure **1c**. When applying limited angular tomography, it was possible to obtain a 3D image of features aligning with the beam directions even with a total body exceeding the limits of the actual beam line. The positions of the cross section images (Figure **5a**) are shown in the diagram of the panel **5b**. As expected, the glue layers and those parts of the annual rings matching with the beam directions were clearly seen in the cross section and from the front. It should be mentioned that the central glue layer consisted of a resin based material in difference to the others. In addition, two distinct features have been detected, an inclusion putatively consisting of resin that is linked to the central glue layer and some lumps of glue obviously squeezed into the void of a groove running through the whole body of the glulam girder. This void was visually detectable at the bottom ant the top of the specimen. The inclusion is presented in all three sections, from top (1), the front (2) and from the side (3). The lumps of glue appeared together with the glue layer in the lateral view (3).

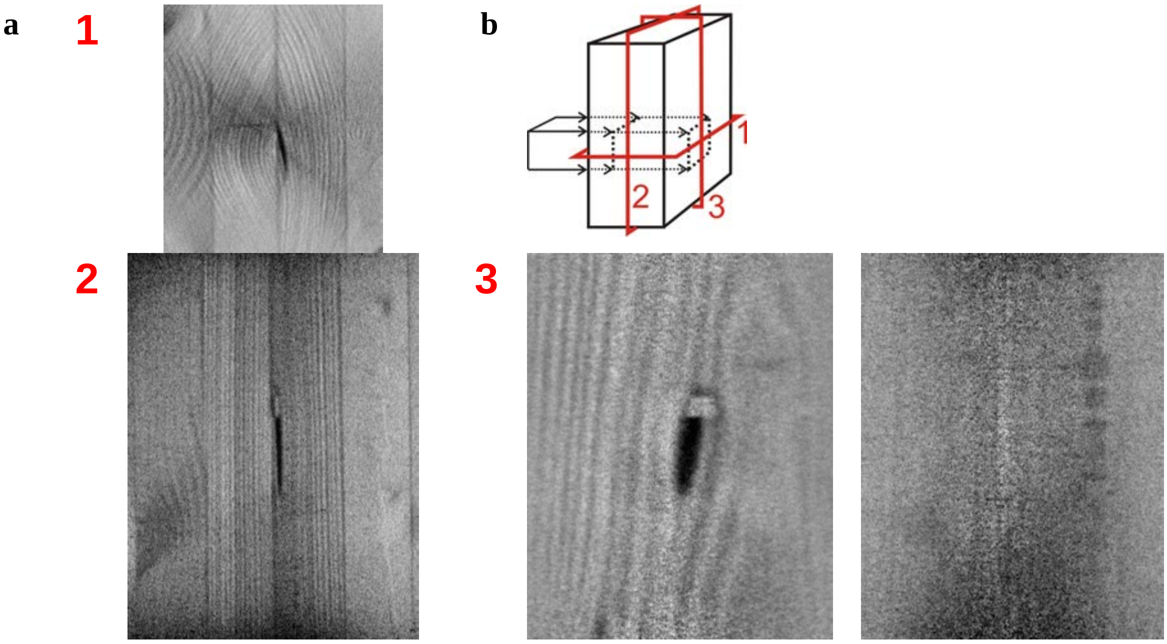

Figure 5: Fast neutron tomography of a glulam girder,
a) reconstructed sections, **b)** positions of the sections. There are two different layers in the lateral view (**3**) showing different features, an inclusion and lumps.

Conclusion

Fast and thermal neutrons have profoundly different penetration limits through wood. While the former ones only could reach 2 cm the latter ones were capable to penetrate 20 – 30 cm. This and the size of objects that might exceed the cross section of the beam line restrict the possibilities of tomography studies. Depending on the shape of certain specimens such as boards it might be possible to penetrate perpendicularly to the broadside so some limited regions of interest could be investigated regionally. But this also means that there is no access in any longitudinal direction. In such a case, tomography is realisable with a limited set of angles as demonstrated. It was shown that this could be achieved by applying a reconstruction approach involving the slice theorem rather than with e.g. a filtered back projection. Features parallel to the beam directions have successfully been reconstructed while leaving those running perpendicularly were omitted without leaving artefacts. By this way, it was possible to study the heterogeneous density distribution in glue layers of boards or in glulams. It further allows studying certain regions within larger objects not fitting completely into the beam line.

References

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