BL20XU (Medical and Imaging II)

1. Introduction

BL20XU is the medium-length undulator beamline with the total length of 245 m. Using this characteristic, a multiscale CT has been installed. The system consists of a micro-CT using projection optics as a wide-field and low-resolution (WL) system and a nano-CT using a full-field X-ray microscope as a narrow-field and high-resolution (NH) system.

2. Multiscale CT for nondestructive nanoscale observation of bulk samples

Multiscale CT realizes both a high spatial resolution and a huge field of view by combining multiple tomographic systems with different fields of view and spatial resolutions. The WL system is used to capture the entire object, and the NH system precisely measures its region-of-interest (ROI). In general, it has been difficult to realize such measurements nondestructively because a probe must have two contradictory characteristics such as a high penetration to transmit a large object and a high interaction with matter for high resolution and high sensitivity. We overcome this problem by employing a newly developed phase-contrast high-energy X-ray nano-CT as the NH system. In most cases, the Fresnel zone plate (FZP) is used as an objective. Its X-ray energy range is restricted to around 10 keV or lower because realizing a high efficiency is difficult in the high-energy region where a high aspect ratio of the zone structure is required. We developed an apodization FZP (A-FZP) with a comparably high efficiency in the high energy X-ray region [1]. Moreover, the very large total beamline length, which is a unique feature of BL20XU, is suitable for high-magnification imaging in the high-energy region. Because the focal distance of FZP is proportional to the X-ray energy, it becomes more difficult to design a high-magnification system inside an experimental hutch as the X-ray energy becomes higher. A distance of 165 m between the first and second experimental hutches of BL20XU makes a magnification of more than 100 times possible even in an X-ray energy range higher than 20 keV. To realize a high interaction with matter, the Zernike phase-contrast method, which shows an interaction that is 10–1000 times larger than the conventional absorption contrast, is employed. Hence, the nano-CT system enables nondestructive three-dimensional imaging of light metal material with 1-mm diameter, 150-nm spatial resolution, and several % of density resolution.

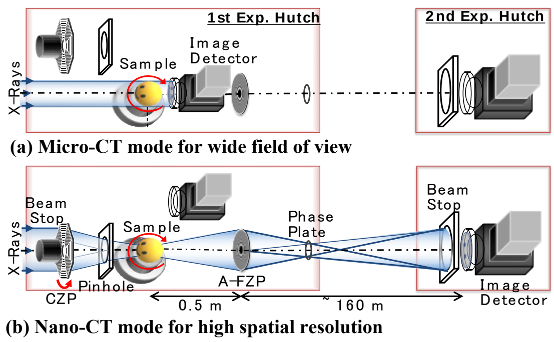

Fig. 1. Schematic drawing and typical parameters of multiscale CT at BL20XU.

Figure 1 schematically depicts the multiscale-CT system at BL20XU. The system consists of a micro-CT as a WL system and a high-energy phase-contrast X-ray nano-CT as a NH system. Users can easily switch between systems, and the available X-ray energy range is 20–30 keV. The typical field of view and the voxel size of the micro-CT are 1 mm and 0.5 µm, respectively. Those of the NH system are 60 µm and 30 nm, respectively. The typical measurement time of nano-CT is around 1 h for 1,800 projections. More details of the system are shown elsewhere [2].

Figure 2 shows a typical measurement example of a multiscale-CT, nondestructive observation of interior-originating fatigue cracks in a titanium alloy Ti-4Al-4V [3]. A micro-CT measurement for entire body of a sample with 0.45 mm was initially performed to identify the position of the interior fatigue crack (Fig. 2a). Then the identified interior region was observed nondestructively with the nano-CT mode (Fig. 2b). The micro-CT image reveals where the internal cracks are located (circled region in Fig. 2a), but the spatial resolution is insufficient to observe the details. Nano-CT image clearly shows the 3D positional relations between the (α + β) dual phase microstructure and the initial cracks. It can also reveal their propagation processes by employing *in situ* measuring methods. Multiscale CT is routinely used in a variety of fields such as metallic materials, ceramics, astronomy, batteries, and devices for nondestructive 3D nano-imaging of bulky sample. Because bulky samples are much easier to treat than tiny samples, the multiscale CT is also frequently used for four-dimensional nano-imaging such as *in situ, ex situ, and operando* measurements. This work was supported in part by RIKEN.

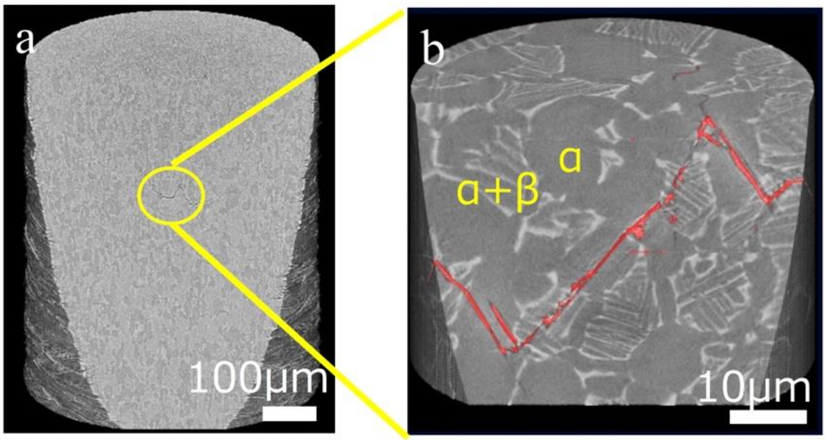

Fig. 2. Multiscale-CT images of interior fatigue cracks in Ti-4Al-4V. (a) Micro-CT image. (b) Nano-CT image of the circled region in Fig. 2a. X-ray energy is 20 keV.

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References:

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