Fusion Engineering and Design 88 (2013) 1613–1618

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Characterization of superconducting wires and cables by X-ray micro-tomography

Ion Tiseanu [a,*], Louis Zani [b], Teddy Craciunescu [a], Florin Cotorobai [a,c], Cosmin Dobrea [a], Adrian Sima [a]

[a] National Institute for Laser, Plasma and Radiation Physics, Atomistilor Street 409, Bucharest, Magurele, Romania
[b] JT60-SA EU Home Team, Fusion for Energy, Boltzmannstrasse 2, 85748 Garching, Germany
[c] National Institute for Material Physics, Atomistilor Street, 105bis, Bucharest, Magurele, Romania

HIGHLIGHTS

- A methodology in support of quality controls monitoring of Cable-in-Conduit-Conductor (CICC) to be used in tokamak magnet systems was developed.
- High resolution (≈40 μm) X-ray tomography images of CICC section up to 300 mm long have been obtained.
- All constitutive elements of CICC (316SS jacket, NbTi and Cu strands and external wrapper foil) can be noninvasively inspected.
- Derivation of quantities like void fraction and void homogeneity at the local and global level, automatic identification of individual NbTi and Cu strands.
- Derivation of geometric parameters like: trajectory, pitch angle and their space distribution.

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form 19 March 2013
Accepted 20 March 2013
Available online 12 April 2013

Keywords:
X-ray tomography
Cable-in-Conduit-Conductor (CICC)
Superconductor
NbTi.

ABSTRACT

Due to their mechanical strength and ability to withstand the large electromagnetic force applied to the superconductors in large magnets during excitation, the Cable-in-Conduit-Conductor (CICC) type superconductors will be employed in the next stage of fusion magnets. Here, we discuss the recent results on the application of a non-invasive method for the characterization of CCIC by X-ray micro-tomography (μXCT). The experiments have been carried out on a high resolution X-ray tomograph in INFLPR (http://tomography.inflpr.ro). An open type nanofocus X-ray source with maximum high voltage of 225 kVp at 15–30 W maximum power and multiple targets of W on different windows materials (Be, Al, Cu or diamond) is the main component. X-rays are detected by means of amorphous silicon flat panel sensor in the cone-beam configuration and high-energy efficient line sensor based on individual scintillators in the fan-beam scanning configuration. The quality of tomographic images (≈40 μm space resolution) allowed the majority of strands of analyzed CICC samples to be fully reconstructed along the investigated segment (up to 300 mm long). Our method provides: (i) local and global void fractions (over a 300 mm length of the sample), (ii) void homogeneity factor as the ratio between void space surface and perimeter and (iii) twist pitch angle of individual strands and its distribution in 3D. It can be used to investigate superconducting CICC during their manufacture, installation or after service inspection, for purposes of QA, characterization or development.

1. Introduction

Due to their mechanical strength and ability to withstand the large electromagnetic force applied to the superconductors in large magnets during excitation, the Cable-in-Conduit-Conductor (CICC) type superconductors will be applied in the next stage of fusion magnets. Thus, the PF coil in ITER [1], TF coil in JT-60SA [2] and the Wendelstein 7 magnet system [3] would rely on twisted multifilament NbTi-based composite strands bundled together with copper strands. The whole bundle is jacketed in a stainless steel sheath to form the CICC. In the literature [4,5] it is argued that such parameters of the inner structure of CICC as the strand twist pitch (TP) and void fraction (VF) have a substantial impact on the CCIC performances.

Here, we discuss the recent results on the application of a non-invasive method for the characterization of superconducting cables by X-ray micro-tomography (μXCT). The experiments have been carried out on a high resolution X-ray tomograph in the National Institute for Laser, Plasma and Radiation Physics. An open type nanofocus X-ray source (FXE-225.51, YXLON International GmbH)

* Corresponding author. Tel.: +40 214574490; fax: +40 214574243.
E-mail addresses: tiseanu@infim.ro, ion.tiseanu@gmail.com (I. Tiseanu).

0920-3796/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fusengdes.2013.03.065

with maximum high voltage of 225 kVp at 15–30 W maximum power and multiple targets of W on different windows materials (Be, Al, Cu or diamond) is the main component. X-rays are detected by a high-resolution amorphous silicon flat panel sensor in the cone-beam scanning configuration (CBCT) and high-energy efficient line sensor (X-Scan-f3-iHE from DT Detection Technology) based on individual scintillators in the fan-beam scanning configuration (FBCT).

Tomographic image reconstructions are obtained by a highly optimized proprietary code with visualization and 3D virtual navigation within the reconstructed volume capabilities. The reconstructed volume is post-processed by proprietary algorithms in order to compensate for the inherent tomography artifacts. Our method provides: (i) determination of the local and global void fraction (over a 300 mm length of the sample), (ii) void homogeneity factor, related to the ratio between void space surface and perimeter in 2D cross-section and (iii) twist pitch angle of individual strands and its distribution in 3D. The determination of the strand trajectories along the sample in 3-D coordinates format represents the key ingredient for obtaining these parameters.

This methodology is used for the quality control monitoring of NbTi CICC for JT-60SA TF coils: "Extended geometry". It can be extended to the non-destructive inspection of CICC after a period of service and even to CICC joints.

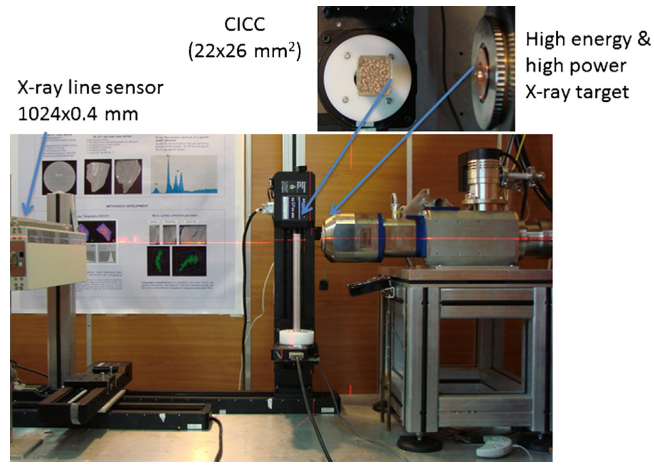

Fig. 1. View of the INFLPR 2D µXCT.

The first section of this paper deals with the selection of the appropriate CT scanning method capable to generate quality CT images on CICC samples of interest. In the second section, follow the qualitative analysis of the tomographic images in respect to

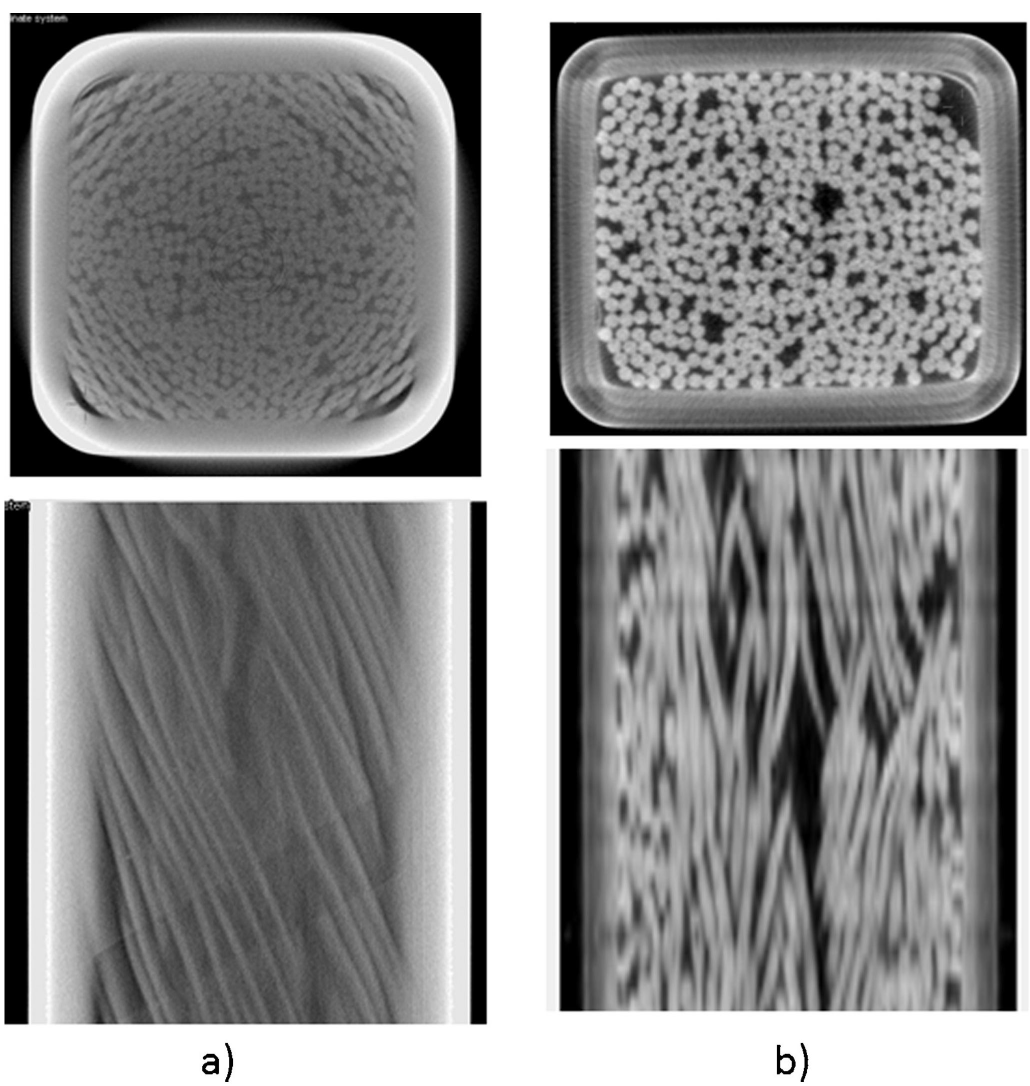

Fig. 2. Cone beam (a) versus fan beam (b) µXCT.