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ScienceDirect

Physics Procedia 69 (2015) 388 – 391

Physics
Procedia

10 World Conference on Neutron Radiography 5-10 October 2014

Wave effect neutron radiographic imaging Origins in WCNR and prospects for low cost systems

J. P. Barton*[a] and J. D. Rogers[b]

[a]*Retired*
[b]*RadSci Consultancy Ltd, 23 Pant-y-Seren, Tonyrefail, South Wales CF39 8DX, U.K*

Abstract

The origins of wave effect neutron test methods for advanced neutron radiography as published in World Conference on Neutron Radiography (WCNR) series has been reviewed. They include Neutron Holography demonstrated at the Dido reactor, Harwell, UK; Neutron Refraction and Small Angle Scattering demonstrated at the IR-8 reactor, Kurchatov Institute, Moscow, Russia; and Neutron Interferometry demonstrated at the ILL reactor, Grenoble, France. Each case presents encouraging evidence that the advanced techniques currently practiced at the most advanced shared-user facilities could be built upon at some lower cost, single-user facilities if the lessons of the original low cost experiments are studied.

Keywords: Neutron Radiography; Neutron Imaging; Neutron Radiographic Imaging; Wave Effect Neutron Radiographic Imaging

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1. Introduction

The objectives in this paper are to review the origins of wave effect neutron test techniques published in the World Conference on Neutron Radiography (WCNR) series, and to ask if recent progress at high cost, shared-user systems could be followed at lower cost, single user systems, by use of custom facility design and longer exposure times. The term Neutron Radiographic Imaging (NRI) is used to mean advanced methods developed primarily for

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* Corresponding author. Tel.: +18584888811
E-mail address: johnpbarton@gmail.com

doi:10.1016/j.phpro.2015.07.054

microscopic research. Thus NRI is regarded as a sub-field of the broad field Neutron Radiography (NR) as used in the conference title. The paper focusses on Neutron Holography, Neutron Refraction, and Neutron Interferometry.

2. Neutron holography-Some origins published in WCNR

A simple hologram is, in effect, an infinite collection of shadowgraphs of a zone plate placed between the scattering centers and a detector. The origins of neutron holography published in the WCNR series, Beynon et al. 1981, enlarged on work briefly reported the preceding year, Beynon and Pink (1980). The neutron source was a cold neutron beam on the Dido reactor at AERE Harwell, UK. At a collimation ration of 500, the neutron flux was about 4 x 10^7 n cm^{-2} s^{-1}. A Fresnel zone plate of 47 alternating rings of aluminum and gadolinium was placed between the scattering specimens and image recorder which was gadolinium foil and Kodak Industrial C film. The exposure time of one hour corresponds to a neutron fluence of about 10^{10} n cm^{-2}. Every object scattering point is represented at the detector by a zone plate pattern containing three-dimensional information. The lateral position of each object point is represented directly at the detector. The distance of the object point is represented by the size of the pattern at the detector. The scattering intensity at each object point is represented by the detected intensity. Reconstruction was done optically by illuminating a photographically reduced version with converging light from a He-Ne laser. The paper in WCNR-1 provides several demonstrations of the feasibility of neutron holography for objects up to 30 mm in diameter. Foreseeable advantages and limitations of this sub-field of neutron radiography are discussed.

A recent review of the diverse potential on neutron holography techniques has been published by Sur et al. (2009) using the advanced neutron source facilities at Chalk River Laboratories, Canada.

The detailed technique information given by the early authors on neutron holography, combined with the technique advances in recent years, suggest how low cost, single-user facilities could make valuable contributions to the field. Firstly, digital detectors and data analysis could provide advantages over the original demonstrations. Secondly, longer exposure times could compensate for the higher neutron fluxes available at advanced shared-user facilities. Thirdly, there is the ability to custom design a sole user facility to meet the special needs of the project.

3. Neutron refraction and small angle scattering-Some origins published in WCNR

Allan and Ross (1981) published a paper in WCNR-1 entitled “The influence of multiple refraction effects on the sharpness of neutron radiographs of ferromagnetic materials”. They demonstrate both refraction and small angle scattering effects using the cold 6H beam at the Harwell reactor Dido. The beam filter of liquid nitrogen cooled polycrystalline beryllium provided an effective neutron spectrum cut off above 4.25 Angstrom units. The collimation L/D ratio was above 500. The imaging was by gadolinium foil and film.

Subsequent papers on neutron refraction and small angle scattering in the WCNR series include those published by Podurets et al. (1992), and Kvardakov et al. (1992) from the Kurchatov Institute, Moscow. These enlarged on previous work by the same team, Podurets et al. (1989).

The methods employed the high angular resolution achievable using a double crystal spectrometer with perfect crystals. The neutron source was the IR-8 reactor operated typically at 4 MW power. The neutron beam incident on the object had a square cross section of side 2 cm. The double crystal spectrometer used perfect crystals of germanium (Ge 111). The beam intensity at the object was 4 x 10^3 n cm^{-2} s^{-1}. The detection used foil and film. Pairs of radiographs are published comparing what they named conventional Absorption Neutron Radiography (ANR) with what they termed “Neutron Radiography at High Angular Resolution” (NRHAR).

These papers published in the WCNR series demonstrated an impressive variety of potential applications. Refraction demonstrations included 1) Castings of alloys (Ti and Al); 2) Cracks (Cu and sapphire); 3) Domain structure (Fe-Si single crystal ferromagnetics); 4) Gradients in inhomogeneous magnetic fields. Small Angle Scattering (SAS) demonstrations included 1) Porosity (pressed and sintered materials); 2) Precipitations (alloys nitride in Ti, Hydride in Nb); 3) Composite materials (Nb-Ti fibers in Cu matrix); and 4) Domain structures (Fe, Co, Ni, Gd polycrystals).

The proceedings of the Fifth World Conference on Neutron Radiography (WCNR5) includes further reporting on double crystal spectrometer from the Moscow group (Podurets et al. 1997), and significant advances initiated using a double crystal spectrometer at the Berlin center (Treimer W. 1997).

4. Neutron interferometry and phase contrast-Some origins published in WCNR

Rauch working mainly with the relatively low-powered Triga reactor at the Atominstitute in Vienna, Austria, has been a contributor to the Neutron Radiography Newsletter since 1968 and a contributor to conferences on Neutron Radiography since 1973 (Manoussakis et al, 1973).

A paper by Rauch (1996), published in WCNR-5, is entitled "Neutron phase topography for high sensitivity material testing". This paper reports experiments with the higher flux ILL reactor at Grenoble, France, to demonstrate neutron interferometry uses for neutron phase sensitive measurements. Features of a perfect crystal interferometer (silicon) combined with a position-sensitive neutron detector, permit detection of phase shifts due to in-homogeneities of various objects. Results presented include so-called "phase topographic visualization of magnetic domains".

Neutron interferometry and phase contrast is extensively discussed in a recent book by Rauch and Warner (2000).

5. Recent reviews including wave effect neutron radiographic imaging

A recent extensive review is provided by scientists from Berlin (Treimer et al 2005). Book chapters titled "Neutron Tomography" (Treimer 2009), and "Neutron Phase Imaging" (Pfeiffer 2009) provide over fifty pages on related progress. Another extensive review is by six authors from Berlin (Strobl et al. 2009) which includes 135 references, but none from the WCNR series prior to WCNR7, probably due to the difficulty of access. Subsequent related publications include "on Coherence in Neutron Imaging" (Treimer and Feye-Treimer 2011). In the Proceedings of the Seventh International Topical Meeting on Neutron Radiography (ITMNR7) special attention is drawn to two papers: " A review of significant advances in neutron imaging from conception to the present" (Brenizer 2013) and to "Imaging of quantum mechanical effects in superconductors by means of polarized neutron radiography" (Treimer et al. 2013). Further developments traceable to the origins of wave effect neutron radiographic imaging as outlined in this paper are described in "Neutron Optics Requirements for Neutron Imaging Techniques" (Lehmann et al. 2014).

6. Summary

In this review, attention has been drawn to some early publications on wave effect neutron radiographic imaging. In comparison, the reviews of advanced NR Imaging techniques refer primarily to capabilities at advanced, expensively equipped, shared-user facilities.

But in addition to such high cost facilities there are a large number of relatively low budget neutron sources available around the world. A question then is can these generally lower flux systems build upon the advances in digital technology pioneered at the shared-user facilities?

Access to data in some early publications on wave effect neutron radiographic imaging could assist those at low flux, single-user neutron facilities

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