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Title: MACROSTRAIN MEASUREMENT USING RADIAL COLLIMATORS AT LANSCE

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Macrostrain measurement using radial collimators at LANSCE

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ABSTRACT

A series of "short" radial collimators have been implemented in the 90° scattering geometries on the neutron powder diffractometer at Los Alamos. The capability to perform macrostrain measurements has been improved by the commensurate ability to rapidly select a sampling volume appropriate to the specimen. The compact design of the collimators was dictated by the need to fit them in a cylindrical vacuum chamber as well as providing space in which to manipulate a specimen in three dimensions. Collimators of different vane lengths were fabricated to give 4 different resolutions for which 2/3 of the diffracted intensity comes from distances of 0.75, 1.25, 2.5 and 4mm along the incident beam. Qualifying scans and a demonstration on a cracked ring, containing a steep stress gradient, are included.

Keywords: neutron, macrostrain, radial collimators, NPD, sampling volume.

1. MACROSTRAIN MEASUREMENT AT A PULSED SOURCE

Spatially resolved measurements using neutrons of macro-residual strains are performed, by masking a sampling volume (from which diffraction to a detector is possible) and then, by moving a specimen through it, examining different internal positions. Definition of the incident and diffracted beams is a prerequisite but, for the diffracted beam, is performed differently at a pulsed than at a steady state source, because of the different detection philosophy of the scattered radiation. In either case, incident collimation is simple, using an aperture in a cadmium or boron based mask to define an approximately parallel incident beam. However for a spectrometer at a pulsed source, neutrons scattered in all directions are eligible for detection, in contrast to a steady state diffractometer for which the neutron intensity is scattered at discrete angular positions. Using the time-of-flight method, the wavelength of a neutron detected in any direction to be determined. Thus, individual detectors that collectively subtend a continuous range of angles simultaneously record spectra which are combined to give a single spectrum. Indeed, the combined summation over a range of angles is usually necessary for effective count times.

The distinction between having usable diffracted intensity over a range instead of concentrated at one angle affects the manner in which collimation is used to define the sampling volume dimension parallel to the incident beam. For monochromatic diffraction, since the diffraction is at an approximately fixed angle, a single slit aperture is sufficient and may be several centimeters from the object (although it is preferable to keep it closer). For acceptable count times at a pulsed source, radiation over a spread of angle must be collected simultaneously. Thus a single aperture is ineffective unless it is very close to the incident beam since parallax rapidly expands the sampling volume.

At LANSCE early attempts to use a single diffracted beam slit close to the incident beam did give good results for measurements in flat specimens[1]. The averaging in strain direction of 5.5° that results from summing over an 11° detector proved negligible compared to changes in the macrostrains between principal directions. Nevertheless the approach was limited to in-plane profiles in plate specimens because the aperture was usually placed in contact with the surface (to minimize the distance to the incident beam). This impeded the manipulation options in one dimension precluding through-thickness scans or objects with irregular geometries.

At ISIS these problems were overcome using radial collimators pioneered on the ENGIN instrument. Using two permanently mounted radial collimators, spatial resolution along the incident beam of 3mm was shown to be possible with a distance of 15cm between the sampling volume and the front of the collimator. This space buffer allowed objects of irregular geometry to be easily translated and rotated into various positions.

2. RADIAL COLLIMATORS

Spatial resolution for measurements of macro-residual strains is achieved by restricting the (90°) diffracted radiation to a short distance along the incident beam. Radial collimators can achieve this. The concept is simple; thin vanes opaque to neutrons are placed in a divergent pattern from a common point (Figure 1a). The important parameters (Figure 1b) are the number (NV) and length (LV) of vanes, their angular separation (α), the separation (R) between the front of the collimator and the sampling volume, and the closest separation (FS) of individual vanes. The weight in the diffracted spectrum given to any point in the sampling volume is proportional to the total angle of detector visible at that point. A plot of distance along the incident beam against angle subtended at a detector is triangular, falling from a maximum at the focal point to zero at ±XMAX. The base of the triangle determines the limiting spatial resolution and is determined by the geometry and vane separation.

The starting point in designing a radial collimator is the value of XMAX which is half the base of the triangular resolution function, and 2/3 of the diffracted intensity reaching the detector comes from the same distance. Selection of XMAX is experiment dependent. Problems involving steep stress gradients require small sampling volumes and small XMAX values, whereas modest stress gradients may use larger sampling volumes that need smaller count times per measurement and make more efficient use of beam time.

Having specified the (XMAX) spatial resolution, selection of LV, NV, and α becomes a compromise between the number of vanes in the collimator, the distance between the collimator and the sampling volume, and whatever physical constraints are imposed by the instrument. One principal objective is to provide as much free space as possible around the sampling volume in which irregularly shaped objects can be translated and rotated with impunity. However the desire to maximize R is limited by fabrication constraints concerning the minimum spacing between vanes, and by their finite thickness which shadows part of the detector.

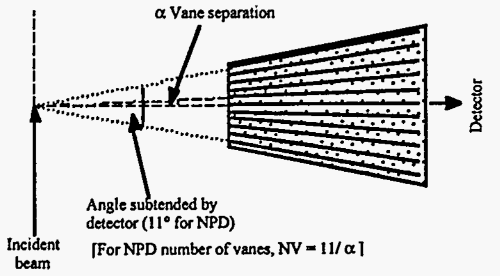

Fig. 1a. Schematic showing radial collimator with respect to the incident beam.

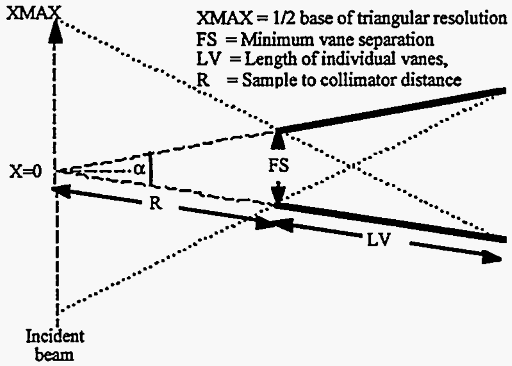

Fig. 1b. Schematic for one vane separation -- grossly distorted for clarity.

3. NEUTRON POWDER DIFFRACTOMETER (NPD) - RADIAL COLLIMATORS

Specifications for the radial collimators were chosen to give XMAX values of 4, 2.5, 1.25 and 0.75mm. The inner radius of the NPD chamber is 370mm, thus to allow clearance between each collimator and the chamber wall we required that R+LV=350mm. Each 90° detector subtends 84.5° to 95.5°, thus the number of vanes, is = 11° / α. For simplicity of manufacture a constant angular separation of 0.31° was used and vane lengths were altered to give the nominal spatial resolutions. The principal difference between the NPD collimators and those at ISIS is that, at ISIS, the vanes extend all the way between collimator and detector - offering ultrafine angular resolution at the expense of mobility. Installation of ISIS style collimators on the NPD would be impractical because the detectors are 1.5m from the sample position and are separated by the wall of a vacuum chamber. Fortunately in almost all problems, ultrafine angular resolution is not needed. Accordingly we faced a choice between placing the collimators inside or outside the chamber. A collimator outside the vacuum chamber would have been substantially longer than those described below precluding rapid manual interchange. Fortunately short vanes can provide the required spatial resolution without unacceptably impeding on the free volume around the specimen, as shown in table 1 and graphically in Figure 2.

Collimator	R	LV	α°	NV	FS	XMAX
1	240	110	0.31	37	1.3	4.0
2	200	150	0.31	37	1.08	2.5
3	140	210	0.31	37	0.76	1.25
4	100	250	0.31	37	0.52	0.75

Table 1 Design parameters for short radial collimators on NPD (lengths in mm)

For the longest vanes, i.e., the best spatial resolution (smallest XMAX) the closest vane separation is 0.52mm and the distance between sampling volume and collimator is 100mm. Conversely for the poorest spatial resolution collimator, the space between the sampling volume and collimator is 240mm. Approximate transmissivities that account for the finite vane thickness are 92.9%, 91.5%, 88.4%, 83.9% for the shortest to longest vane lengths respectively. The vanes are 110mm tall, which exceeds the maximum possible beam height including the vertical divergence of the Debye cones.

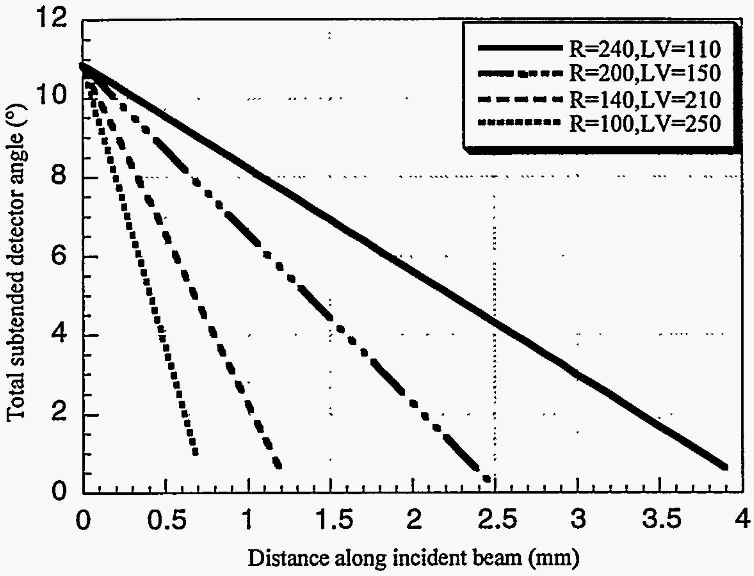

Fig 2. Nominal resolution (symmetrical in x) of the 4 different NPD collimators. In all cases the vane separation is 0.31°. The calculation does not account for the finite vane thickness, thus the maximum subtended angle is 11°.

4. FABRICATION AND MOUNTING

A standard choice for vane materials is mylar coated with gadolinium oxide paint. The techniques used to precisely stretch large numbers of mylar vanes on a divergent pattern, without wrinkling or kinking (which would render the collimators useless) are difficult to achieve and require considerable experience. Three manufacturers were approached; Eurocollimators in the UK (formerly L&H designs), JJ X ray in Denmark and Ohashi Industries in Japan. The manufacturing approach of each was subtly different and ultimately we selected Ohashi industries. Their construction used a frame and spacers made of epoxy-glass fiber, and vanes comprising mylar sheets 50µm in thickness with 25µm of GdO_2 paint on both sides. Each collimator was manufactured with a carrying handle and the weight of the longest was less than 5 kg, thus they are easily maneuverable. A photograph of the 4 collimators is included in Figure 3a.

Fig. 3a. Collimators of varying length can easily be exchanged to provide different sampling volumes as warranted by the experiment.

Fig. 3b. View along incident beam path. In the foreground is the incident Boron nitride mask. The radial collimators are mounted on either side of the specimen (a Titanium fan blade in the background).

One concern in interchanging the collimators for different experiments is the need for accurate alignment and repositioning. The center of the sampling volume must be reproducible to at least 0.1mm. Since the back face of each collimator is 350mm from the sampling volume even small errors in angle or position can displace the actual from the nominal center of the sampling volume. To minimize this possibility each collimator is mounted on a precision inverted V-base which mates with permanently mounted supports on the equipment that provides XYZ motion for the specimen. Each support can be precisely moved parallel, perpendicular or rotated using optical slides. These are shown in Figure 3b.

5 TESTING AND DEMONSTRATION

Prior to use, the performance of each collimator was assessed by moving a 3.15mm diameter steel pin parallel to the incident beam through each defined volume. The diffracted intensity (measured as an integral over a range that included several reflections) profile was evaluated by numerically convoluting a triangular resolution function with a function describing the circular (in the horizontal plane) pin. Convoluted intensity profiles are plotted from "first pick up" to "last pick up" in Figure 4. The line types are dotted for the experimental measurements and solid for the predicted profiles using the nominal resolutions in Figure 2. For all 4 collimators the measured and calculated profiles are in close agreement.

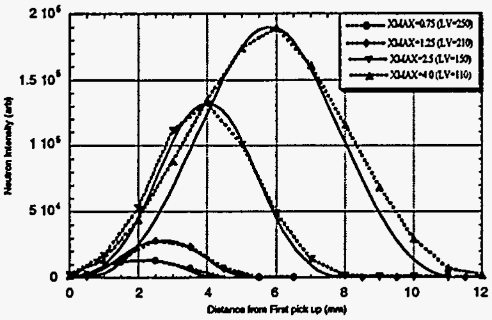

Fig. 4. Measured (dotted) and calculated (solid) profiles for the convoluted intensity of the resolution function with a 3.15mm pin moved along the incident beam for each collimator. Calculated profiles were evaluated numerically

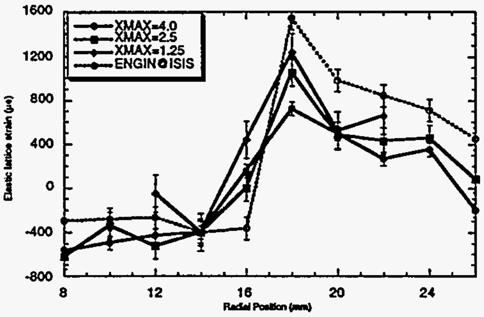

Fig. 5. Strain profiles near a crack tip become progressively sharper with increasing spatial resolution. The NPD data comes from a single peak fit on the [110] reflection whereas the ISIS data are calculated from a Rietveld refinement of the whole pattern.

To evaluate the performance on a real specimen we examined a cracked ring that has been previously studied[2]. The ring was 5mm thick and contained a fatigue crack partially propagated through an autofrettage residual stress distribution. The resulting redistribution produces a steep strain gradient around a radial position of 16mm. In that region, over approximately 4mm, the hoop strain increases from a compressive value of -400μstrain to a tensile value of close to 2000μstrain. This demands small sampling volumes to satisfactorily resolve the change between extremes, but also provides a test specimen in which the increasing spatial resolution provided by the collimators can be monitored. In practice we only made measurements using three collimators and did not use the finest spatial resolution (XMAX=0.75). In Figure 5 the maximum to minimum strain variation increases as XMAX is reduced. Also shown in the graph is a comparable scan for ENGIN at ISIS which shows the largest strain variation - although the strains are calculated differently for the two instruments, so are not directly comparable.

7. ACKNOWLEDGMENTS

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