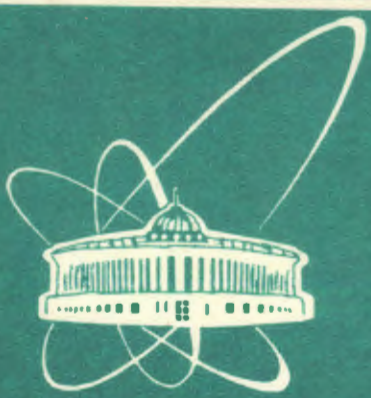

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POSSIBLE UTILIZATION OF HIGH RESOLUTION FOURIER DIFFRACTOMETER AT REACTOR IBR-2 FOR STRAIN MEASUREMENTS

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INTRODUCTION

In the last 10 years thermal neutron diffraction has been intensively used as the new method for non-destructive test of internal strains in bulk materials (see, e.g., review [1]). Currently most of strain measurements are made on the diffractometers operating with the conventional steady state reactors. However, experience of such measurements on neutron diffractometers at pulsed neutron sources of RAL (HRPD) [2], GKSS (FSS) [3], PNPI (mini-SFINKS) [4], ANL (GPPD) [5] and LANSCE (NPD) [6] demonstrates essential advantages of the latter. The main is the possibility of simultaneously measuring many reflections, up to 15 in the case of steel.

The new high resolution reverse time-of-flight Fourier neutron diffractometer HRFD [7] currently operating at the high flux pulsed reactor IBR-2 in Dubna opens good perspectives for carrying out strain measurements for applied purposes.

THE EXPERIMENTAL SET-UP

The diffractometer HRFD is installed on beam No.5 of the IBR-2 reactor. The reactor design permits use of two neutron moderators - the room temperature water and the cold methane one. In the first case the total thermal neutron flux on moderator surface (the visible area of 400 cm^2) is equal to 10^{13} $n/cm^2/s$. At a distance of 9 m from the moderator a Fourier chopper is installed. The neutron beam before the chopper is formed by a straight, mirror neutron guide and after the chopper - by a focusing, curved mirror neutron guide of 19 m length. The incoming and outgoing window cross-section of these guides are 30x200 and 10x100 mm^2, respectively. The sample is positioned at 29 m from the moderator. Having gone through the chopper and the neutron guides the neutron flux at sample position is 10^7 $n/cm^2/s$.

Figure 1 shows schematically the experimental arrangement of the detecting equipment of HRFD. For strain measurements the detector is positioned at the scattering angle of 90°. The strain neutron scanner with which sample displacements are accomplished is fixed on the table of the diffractometer.

THE 90°-DETECTOR

The scintillation type detector consists of five 132 mm diameter photo multipliers. On top of each a ^{6}Li-glass element measuring 102x102x1 mm^3 is mounted. These scintillation elements are spatially arranged (Figure 2 and Table 1) so that to time focuse the scattered neutrons. The distance from the sample position to the middle point in the detector is 1.1 m. The detector has the solid angle of 0.007 sr but it is not used at full (see further). The horizontal dimension of the entrance aperture of the detector is 65 mm. The efficiency - about 70%.

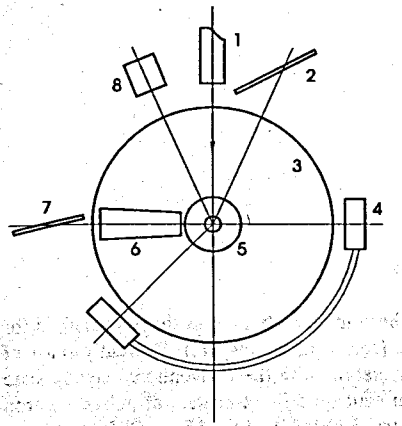


Figure 1. Schematical lay-out of the detecting equipment of HRFD: 1 - mirror guide, 2 - large back-scattering detector, 3 - mounting table of diffractometer, 4 - position sensitive detector, 5 - strain neutron scanner, 6 - soller collimator, 7 - 90°-detector, 8 - detector of midlle resolution.

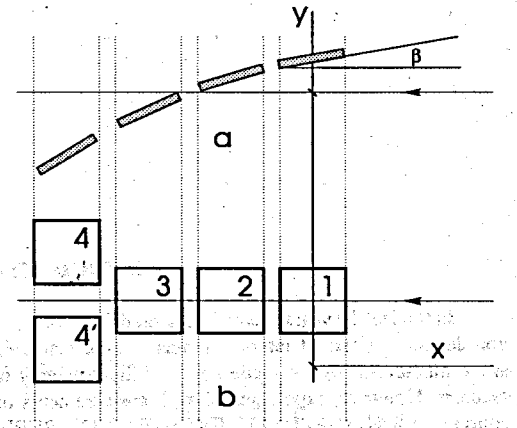


Figure 2. Arrangement of ^{6}Li - glass elements: a - plan view , b - side view. Denotions: β is the slope angle of an element with respect to the outgoing beam direction; x is the distance between the sample position and the centre of an element, y is the distance between the centre of an element and the x-axis. Table 1 summarizes these values and solid angles, ω, of all elements.

Table 1. The geometrical parameters of Li-glass elements

Number of element	x, mm	y, mm	β, degree	ω, msr
1	900.01	23.91	5.23	1.75
2	1060.13	11.50	7.14	1.45
3	1220.18	-5.27	8.99	1.23
4, 4'	1380.24	-26.43	10.79	1.06x2

The important disadvantage of the neutron detectors of the scintillation type is their sensitivity to gamma-rays. This deprives one of the possibility of using the materials with large (n,γ)-cross-section, such as cadmium and gadolinium, for neutron beam collimation and detector background suppression in the measurements with the main large back-scattering detector of the HRFD (Figure 2) in which the light guides between the Li-glass elements and photo multipliers are used to increase the detection solid angle. The accompanying decrease in light scintillation amplitudes leads to a shift of a neutron peak in the amplitude spectrum in the gamma-background range.

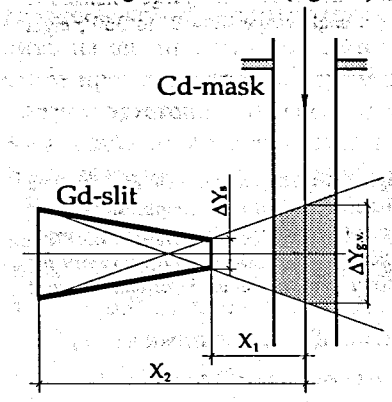
The experiments with the detector without light guides give good separation of the neutron peak from gamma-ray background induced by the Cd sample. Then gamma-background can be suppressed with the help of a conventional linear amplitude discriminator.

The fact that the Li-glass elements are fixed right on the windows of the photo multipliers of the 90°-detector causes decrease of the effective solid angle. In our case this decrease is equal to 10%.

Use of materials with large capture cross-sections simplifies the task of building a collimator system for a neutron strain scanner.

THE COLLIMATOR SYSTEM

To limit the gauge volume inside investigated specimen two collimator systems are used. The first one consists of few changeable Cd-masks before the sample. These masks can vary the gauge volume across the direct neutron beam from 1x1 to 10x10 mm^2. The second is a soller radial collimator with vertical slits formed by gadolinium covered sheets. This collimator limits the gauge volume along the direct beam (Figure 3).



The spatial resolution in this direction to be held by one slit equals:

$$\Delta y_{g.v.} = 2\Delta y_s x_2/(x_2-x_1), \quad (1)$$

the denotions being given in Figure 3. At x_1 = 120 mm, x_2 = 770 mm and a slit width Δy_s = 1 mm one may have $\Delta y_{g.v.}$ = 2.4 mm. In this case an exit size of the slit equals $\Delta y_{s.e} = \Delta y_s x_2/x_1$ = 6.4 mm. For the whole of the detector solid angle to be covered one needs to have 10 slits. The vertical size of a slit has no influence on the spatial resolution.

Figure 3. The central slit of the soller collimator: Δy_s is the width of a slit, $\Delta y_{g.v.}$ is the mean size of the gauge volume along the direct neutron beam.

THE INSTRUMENTAL RESOLUTION

The resolution of the time-of-flight powder diffractometer is:

$$R = \Delta d/d = ((\Delta t_0/t)^2 + (\gamma \cdot ctg\theta)^2)^{1/2}, \quad (2)$$

where d is the interplane distance in angstroms (Å), t is the time of flight, Δt_0 is the width of the neutron pulse, γ includes all geometrical uncertainties, θ is the Bragg angle.

In HRFD we have Δt_0 = 7 μs, L=30 m. Then:

$$\Delta t_0/t = \Delta t_0/(253 \cdot L \cdot 2d \cdot \sin\theta) = 6.5 \cdot 10^{-4}. \quad (3)$$

To estimate the value of t one has to take into consideration the following circumstances: 1) because the 90°-detector is the time-focusing one the angle divergence of the scattered neutron beam does not influence the d-spacing resolution of HRFD; 2) one may neglect the contribution to the d-spacing resolution due to finite dimensions of an investigated sample, if the gauge volume does not exceed 5x5x5 mm^3; 3) the angle divergence of a direct neutron beam is defined by the mirror neutron guide and in our case it is equal to $\gamma = 1.4 \cdot 10^{-3}$ at d = 2 Å. Thus, the d-spacing resolution of the neutron strain scanner is expected to be of $R = 1.5 \cdot 10^{-3}$ at d = 2 Å. Experiments can be made in the d-spacing range from 0.5 to 10 Å.

THE STRAIN NEUTRON SCANNER

To begin the program of investigations of strains in bulk specimens the simplest neutron scanner is designed to accomplish three orthogonal x, y and z displacements of a sample and rotation about the vertical axis. The carrying capacity of this device is 100 kg.

However, with this scanner one cannot measure the full strain tensor |e| in the gauge volume.

To do this the investigated sample must be rotated about the center of the gauge volume so that the scattering vector **Q** which bisects the angle between the incoming and outgoing beams will scan this volume in a rather large angle range. So, the strain e in the direction of the vector **Q** is defined with six components e_{ik} (i, k = x, y, z) of the tensor |e|:

$$e(l, m, n) = l^2e_{xx} + m^2e_{yy} + n^2e_{zz} + 2lme_{xy} + 2mne_{yz} + 2nle_{xz}, \quad (4)$$

where (l, m, n) are the direction cosines of the vector **Q**, and at least six measurements are needed for determination of the tensor |e| in general case.

The simplest from the practical point of view way to perform this rotation is the scanning of the vector **Q** over the surface of the 90°-cone which apex lies in the centre of the gauge volume. For example, if the scan is accomplished with a step of 45° in the angle range from 0° to 360°, eight measurements of e(l, m, n) can be made.

SUMMARY

The study of the HRFD capabilities shows that the designed neutron scanner will have the time and spatial resolution sufficient for determination of residual strain profiles in bulk specimens up to 40 mm depth. The Reitveld profile refinement of all measured reflections gives the strain value averaged over the gauge volume (macrostrain). Good statistics per reflection are not necessary for satisfactory refinement. Fitting of individual reflections allows one to obtain information about microstrains.

REFERENCES

1) Windsor, C.G.: in:Industrial and Technological Applications of Neutrons, Proc. Inter. School of Physics "Enrico Fermi", North-Holland, 1992
2) David, W.I.F., et al.: RAL Communication 86-068, Chilton, 1986
3) Priesmeyer, H.G, Schroder, J.: Mat.Res.Soc.Symp.Proc., 1990, 166, 299
4) Hiismaki, P., et al.: in:Neutron Scatt. in the Nineties, Conf. Proc., Vienna, IAEA, 1985
5) Kupperman, D.S.: Sci. Rev., 1992, 2, 15
6) Bourke, M.A.M., et al.: in Proc. NATO Advanced Research Workshop on Residual Stress, Kluwer Acad. Publ., 1992
7) Aksenov, V.L., et al.: JINR Communication E13-92-456, Dubna, 1992

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