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Yu.V.Nikitenko

NEW DEVELOPMENT OF A SMALL-ANGLE NEUTRON SCATTERING INSTRUMENT FOR A PULSED NEUTRON SOURCE

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1. Introduction

The issues of optimizing the geometric parameters of the small-angle neutron scattering spectrometer have been generally considered quite a long time ago [1-4]. At present the overall consideration of the optimization issues continues, especially in the case of time-of-flight spectrometers [6,7]. But, the possibility of utilizing the wavelength dependence of the neutron emission solid angle within the source - sample flight path, which exists in the time-of-flight technique, was not considered.

2. Proposal and calculation results

The spectrometer scheme for the case of the geometry with diaphragms (pinhole geometry) [8,9] is shown in Fig. 1. For definiteness,we will carry on our consideration in the cylindrical coordinate system. Neutrons with a wavelength λ reach the SL_1 and SL_2 diaphragms at times t_1 and t_2, respectively (the moment of the neutron pulse generation is chosen as an initial moment of time) :

$$t_1 = \alpha L_0 \lambda \quad \text{and} \quad t_2 = \alpha (L_0+L_1)\lambda, \tag{1}$$

where α=m/h, m is the neutron mass, h is the Planck constant, L_0 is the sample - first diaphragm distance, and L_1 is the distance between diaphragms.

We will assume that the radii $R_1(t)$ and $R_2(t)$ of the diaphragm holes are functions of time. In accordance with (1), one may present them as functions of the wavelength: $R_1(\lambda=t/\alpha L_0)$ and $R_2(\lambda=t/\alpha(L_0+L_1))$. Then the intensity $j(\lambda,Q)$ of the scattering within the unit interval of the wavelengths and the unit detector area is :

$$j(\lambda,Q)dS_3 = C\ j_0(\lambda)\ R_1^2(\lambda)\ R_2^2(\lambda)\ dS_3(\theta)\ \Phi(\lambda,Q)\ /L_1^2\ /L_2^2 = j_{in}(\lambda)\Phi(\lambda,Q)dS_3, \tag{2}$$

where $j_0(\lambda)$ is the neutron intensity within the unit solid angle, the unit wavelength interval, and the unit cross-section surface at the position of the first diaphragm, $\Phi(\lambda,Q)= \int F(Q)R(Q,Q',\lambda)dQ'$ distorted scattering law, $F(Q)$-true scattering law, $R(Q,Q',\lambda)$ - resolution function, $dS_3(\theta)$ is the elemental area of the detector at the scattering angle θ, and C is a constant determined by the parameters that are insignificant in our consideration. Further, we will introduce the deviation $\delta N(\lambda,Q)$ of the scattered neutron number connected with the distortion of the scattering law $\delta F(\lambda,Q)$ caused by the finite resolution $\delta Q(\lambda)$ over the scattering vector, and the statistical deviation of the neutron number $\delta N_{st}(\lambda,Q) = (j(\lambda,Q)\cdot t)^{1/2}$, where t is the measurement time. The requirement that $\delta N_{st}(\lambda,Q) / \delta N(\lambda,Q) = MIN$ in the $[\lambda_{min}, \lambda_{max}]$ and $[\theta_{min}, \theta_{max}]$ intervals at given t results in the integral relationship:

$$\int \delta F^2/\Phi \; j_{1n}(\lambda)d\lambda dS_3 = MAX \qquad (3)$$

Equation (3) is not defined fully because δF may be arbitrary. This uncertainty is eliminated if we take into account the following relationships matched with (3):

$$\begin{aligned} &\int (\delta F/\Phi)^2 j(\lambda,Q)d\lambda dS_3 /J = const1, && a) \\ &J= \int j(\lambda,Q)d\lambda dS_3 = MAX, && b) \qquad (4) \\ &L_1 + L_2 = L = const2 && c) \end{aligned}$$

The meaning of (4a,b) is obvious and consists in the following: when $(\delta F/\Phi)^2$ averaged over the scattered neutron spectrum is fixed, the scattered neutron intensity J is maximal. The (4c) expression of the fixed total flight path is commonly used [3].

It is obvious that the equations (4) are not sufficient to determine the relationship $\alpha=L_1/L_2$ and dependence $R_1(\lambda)/R_2(\lambda)$. Therefore, we will impose additional restrictions that often take place in practice. First, the resolution over the wavelength at a

pulsed source is usually sufficient, so we may assume, within some tolerance, that $\Delta\lambda=0$. Further, we will assume that the total resolution is not determined by the detector resolution ΔR, so we also may make $\Delta R=0$. Finally, we will choose certain dependences $R_1(\lambda)=R_{10}f(\lambda)$ and $R_2(\lambda)=R_{20}f(\lambda)$, where $f(\lambda)=(\lambda/\lambda_{min})^n$. Now we can determine parameters α, $\beta=R_{10}/R_{20}$, and n by solving the system of equations $\partial J/\partial x=0$, where $x=\alpha,\beta,n$ (both (4a) and (4c) are met). Independently of $f(\lambda)$, we have $\alpha=1$ and $\beta=2$ for the first two parameters. For some scattering laws and for certain kind of the resolution function, parameter n can also be evaluated analytically. Thus, in the case of the symmetrical resolution function we have $\delta F=-1/2F''\delta^2Q(\lambda)$ [10]. For the scattering law $F_1(Q)=\exp(-wQ)$, we get the index of power n = 1. Fig. 2 shows the dependence $\eta=J(n=1)/J(n=0)$ for w=1A (curve 1), w=10A (curve 2), and w=30A (curve 3). For the calculations, the Maxwellian spectrum $j_0(\lambda)=2\lambda_t^4\lambda^{-5}\exp(\lambda_t^2\lambda^{-2})$ was used, and the following parameters were chosen: λ_t=1.8A, λ_{min}=0.18A, λ_{max}=18A, L_1+L_2=20m. Also,the condition $R_{min}(\lambda)<<R_{max}$=50 cm was used. As follows from Fig. 2, the gain from using the time-dependent diaphragms increases with increasing w.

Dependence of η on the kind of initial spectrum $j_0(\lambda)$ is of interest. Fig.3 shows the dependence of η on parameter λ_t (curve 1) for w=1A. One can see that parameter η decreases with increasing λ_t. Thus, for λ_t=1.8A (which corresponds to the neutron source temperature T=300K) η=25, while for λ_t=7A (T=20K) η=9, and for λ_t=20A (T=2.5K) η is only 1.8. This figure also shows dependence of parameter $\varepsilon=Lg(J(\lambda_t)/J(\lambda_t=1.8A))$ for n=1 at some value of const1 (curve 2). The increase in ε with increasing λ_t points to the advantage of using a colder source. At the same time, the relationship $J(n=1, \lambda_t=1.8A)=J(n=0, \lambda_t=4A)$ is met, which indicates that up to λ_t=4A (T=60K) cooling of the source may be replaced simply by keeping regime with n=1.

Let us consider other scattering laws. For $F_2(Q)=\exp(-w^2Q^2)$, parameter n_{opt}, which is the value of n at η=max, increases with increasing w. Thus, n_{opt}= 1 for w^2 = 1A^2, while n_{opt}=1.31 for

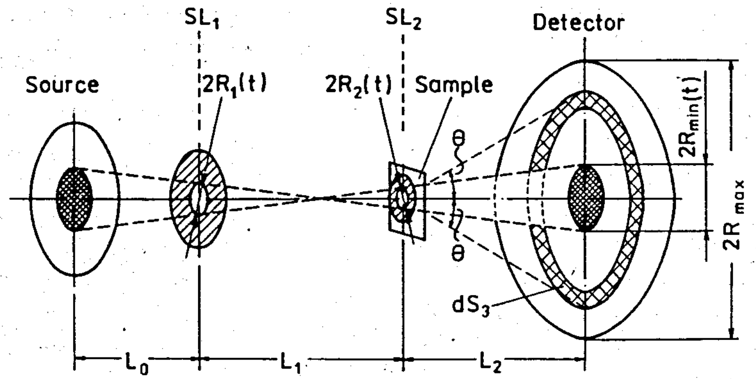
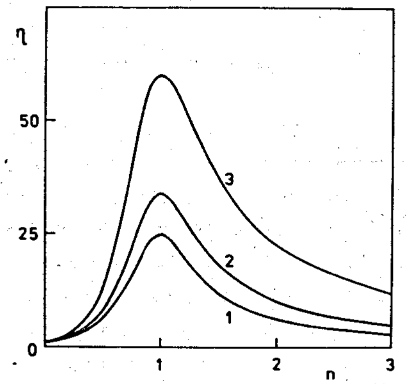


Fig. 1. Layout of a small-angle neutron spectrometer at a pulsed source. SL_1 and SL_2 are the diaphragms with time-dependent hole radii $R_1(t)$ and $R_2(t)$, respectively.



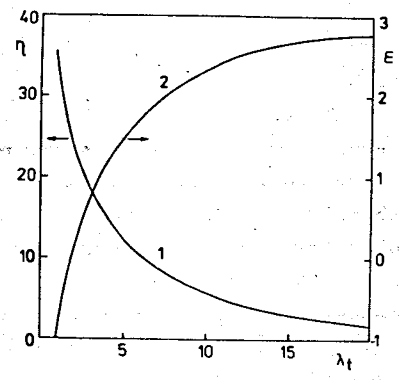


Fig. 2. Dependence of parameter η on the index n of the power law of changing the diaphragm radii for the case of the scattering law F(Q)=exp(-wQ) with the following values of w: w=1A for curve 1, w=10A for curve 2, w=30A for curve 3.

Fig. 3. Dependence of parameters η (curve 1) and ε (curve 2) on the characteristic wavelength λ_t of the Maxwell spectrum for the index of power n=1, scattering law F(Q)=exp(-wQ), and parameter w=1A.

$w^2=1000A^2$. The increase of η with increasing n takes place also for the $F_3(Q)=Q^{-m}$ law. It is interesting in this case that the minimum of η exists at $n\cong-1$.

3. Conclusion

The possibility of optimizing the small-angle scattering spectrometer, which concerns changing the cross-section area of the diaphragms according to a dependence on time exists for the time-of-flight technique. The form of law and related gain in scattered neutron intensity depends on the scattering law. At certain parameters of the spectrometer and the neutron spectrum, this gain may be up to several tens. The proposed operating regime is the most effective at minor distortions of the scattering law, where the neutron intensity is not high. Its use would also be preferable at low-frequency pulsed sources, where a broad wavelength interval is available in a long flight path. For example, the interval of 0.18 to 18 A is accessible at the IBR-2 reactor, whose pulse frequency is 5Hz, for the flight path $L_0+L_1+L_2$ = 44.5m. As a result,there is a possibility to create an extended collimation flight path L_1+L_2 = 30 + 40m, which would allow high angle resolution $(1\div3)\cdot10^{-4}$ rad to be attained at a small-angle facility.

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