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Physica B 350 (2004) e849–e851
PHYSICA B
www.elsevier.com/locate/physb

UFO—a multi-analyser option for IN12

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Abstract

The IN12 instrument is operated by FZ Jülich in collaboration with CEA Grenoble as a CRG-B instrument at the Institut Laue Langevin in Grenoble. As a three-axis spectrometer for cold neutrons it is dedicated for high-resolution studies of low-energy excitations. In the past years the instrument has been continuously improved and it has demonstrated its excellent performance for neutron scattering research. To meet further challenges as a state-of-the-art instrument in the next funding period we will propose to upgrade IN12 with a multi-analyser option similar to planned or existing RITA-type instruments. IN12 will then be optionally equipped with an array of individual analyser blades which can be positioned separately in order to map the scattered beam on a user-chosen path in ($\boldsymbol{Q}$,ω)-space. We refer to this set-up as IN12-UFO (universal focusing option). Both, the feasibility and the scientific case are currently being studied. On the conference we will show details of the planned instrumental set-up and demonstrate its flexibility and multiplex advantages for specific physical applications.

PACS: 61.12.Ex

Keywords: Neutron instrumentation; Inelastic neutron scattering; Three-axis spectrometer; Multiplexing

1. Intention

In recent years the idea of multiplexing on a three-axis spectrometer (TAS) has gained considerable interest. Instead of using a standard focusing analyser the spectrometer will be equipped with an array of individually adjustable analysers in order to measure several different points in ($\boldsymbol{Q}$,ω)-space simultaneously which a conventional TAS only can do one after another. Several concepts have already been realised or are in construction [1]. For the spectrometer IN12 we also plan the upgrade to a multi-analyser array with a position sensitive detector so that IN12 can offer the multiplex advantage as the first three-axis spectrometer for cold neutrons.

2. UFO concept and set-up

In comparison with the standard set-up the use of a multi-analyser array will bring in one more parameter: Different scattering angles for the single analysers. Concerning the scattering equations for momentum and energy transfer this

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doi:10.1016/j.physb.2004.03.220

additional freedom can be transferred to other variables. Two solutions are of particular interest: (a) The same energy transfer for all analysers which will result in a curved path in $\boldsymbol{Q}$. (b) The analysers map a linear path along a chosen direction in $\boldsymbol{Q}$. This implies different energy transfers along the analyser array. In the following, we will focus on this case.

In addition to the scattering conditions there are also constructional considerations which must be taken in account: (a) Components of the existing spectrometer shall be used as far as possible. (b) The multi-analyser array shall be an interchangeable option for the instrument. Since IN12 has an outstanding reputation for special problems where a collimated beam with extremely low background is essential the new construction shall also allow to switch back to standard mode.

Therefore we have chosen a compact solution which can be mounted in the existing analyser housing. There will be interchangeable shielding components for incoming and outgoing beam to have either a wide opening to serve the analyser array or mount a collimator instead. The detector housing will be extended to hold a position sensitive detector (PSD) of about 35 cm width and 17 cm height.

The individual analysers will be positioned similar to the single blades of a standard focusing analyser: again all beams meet at one focus point but in contrast both the position and the scattering angle of the single blades can be adjusted individually in order to map a user chosen path in $(\boldsymbol{Q},\omega)$-space (universal focusing). The PSD is placed well behind the focus point and can therefore detect the different beams in different channels. To prevent a cross-talk between the single analysers a diaphragm is mounted at the focus point. To technically achieve the positioning of the analysers in space they will be movable along parallel rails.

3. Principal equations

For the following calculations we take the centre of the analyser array as a reference in the scattering equations which define a $\boldsymbol{Q}$-vector in dependence of the incoming and outgoing neutron wave-vectors $\boldsymbol{k}_\mathrm{i}$ and $\boldsymbol{k}_\mathrm{f}$. For the other analysers we can then define a deviation of the scattering angle $\Delta\varphi$ and correspondingly a deviation ΔQ and Δk_f. As an additional parameter, we fix the direction of ΔQ and call this angle γ. With this condition the different scattered beams describe a linear path with a step width of ΔQ. The components of the vectors then have the following form:

$$Q\begin{pmatrix}\cos(\psi)\\ \sin(\psi)\end{pmatrix} + \Delta Q\begin{pmatrix}\cos(\gamma)\\ \sin(\gamma)\end{pmatrix} = k_\mathrm{i}\begin{pmatrix}1\\ 0\end{pmatrix} - (k_\mathrm{f}+\Delta k_\mathrm{f})\begin{pmatrix}\cos(\varphi+\Delta\varphi)\\ \sin(\varphi+\Delta\varphi)\end{pmatrix}. \quad (1)$$

The deviation in k_f can further be related to an angular deviation of the analyser Bragg angle:

$$\csc(\theta_\mathrm{A}+\Delta\theta_\mathrm{A}) = (k_\mathrm{f}+\Delta k_\mathrm{f})\, d_\mathrm{A}/\pi. \quad (2)$$

Linear approximations for the Δ-variables are easily achieved. They will be useful for a general estimation and serve as a starting point for numerical calculations. The next step is the calculation of the analyser positions where we use the vectors from the sample to the analysers and the corresponding vectors from the analysers to the focus point. Fig. 1 shows a schematic overview with all relevant variables. The displacement $\boldsymbol{v}$ from the centre analyser is described in terms of the incoming and outgoing beams by the following equations

$$\begin{aligned}\vec{v}/r_\mathrm{A} &= \left(1+\frac{\Delta r_\mathrm{A}}{r_\mathrm{A}}\right)\begin{pmatrix}\cos\varphi_1\\ \sin\varphi_1\end{pmatrix} - \begin{pmatrix}\cos\varphi\\ \sin\varphi\end{pmatrix}\\ &= \alpha\begin{pmatrix}\cos\varphi_\mathrm{A}\\ \sin\varphi_\mathrm{A}\end{pmatrix} - \alpha\left(1+\frac{\Delta r_\mathrm{F}}{r_\mathrm{F}}\right)\begin{pmatrix}\cos\varphi_\mathrm{A1}\\ \sin\varphi_\mathrm{A1}\end{pmatrix} \quad (3)\end{aligned}$$

with the abbreviations

$$\begin{aligned}&\varphi_\mathrm{A} = \varphi + 2\theta_\mathrm{A}, \Delta\varphi_\mathrm{A} = \Delta\varphi + 2\Delta\theta_\mathrm{A},\\ &\varphi_1 = \varphi+\Delta\varphi, \varphi_\mathrm{A1} = \varphi_\mathrm{A}+\Delta\varphi_\mathrm{A}, \alpha = r_\mathrm{F}/r_\mathrm{A}. \quad (4)\end{aligned}$$

For a given ΔQ and hence the angular deviations $\Delta\varphi$ and $\Delta\varphi_\mathrm{A}$ these equations provide an exact solution for Δr_A and Δr_F. Using these solutions we can rewrite the displacement $\boldsymbol{v}$ as

$$\begin{aligned}\vec{v} &= r_\mathrm{A}\csc(\varphi_\mathrm{A1}-\varphi_1)\\ &\cdot\begin{pmatrix}\sin\Delta\varphi\cos\varphi_\mathrm{A1} + \alpha\sin\Delta\varphi_\mathrm{A}\cos\varphi_1\\ \sin\Delta\varphi\sin\varphi_\mathrm{A1} + \alpha\sin\Delta\varphi_\mathrm{A}\sin\varphi_1\end{pmatrix}, \quad (5)\end{aligned}$$

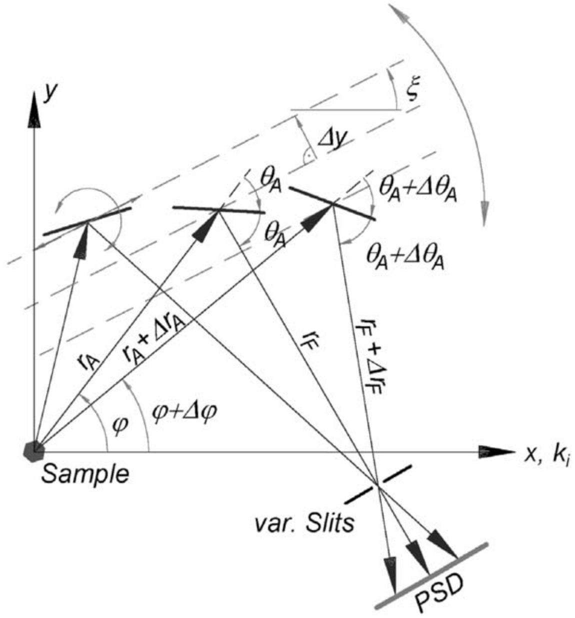

Fig. 1. Scattering paths between sample, analysers and detector with the relevant angles and lengths shown as an example for three analysers. The dashed lines indicate the equidistant analyser rails. It should be noted that lengths and analyser widths are not in scale.

which can be set into relation with the equidistant array of rails. We call this distance Δy and the displacement along the rail Δx. The whole array can be rotated around the centre position (angle ξ). This degree of freedom compensates for the fixed Δy.

$$\vec{v} = \begin{pmatrix} \cos\xi & -\sin\xi \\ \sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}. \tag{6}$$

A further consideration is the angular coverage: With the condition that the analyser array shall have the least gaps or overlaps between each other, seen both from the sample and the focus point, we get two further relations: The distance to the focus point r_F and an relation between ΔQ and the analyser width Δs. In a linear approximation we can write these equations as

$$\begin{aligned} \alpha^{-1} &= r_A/r_F = \Delta\varphi_A/\Delta\varphi \\ &= 1 + 2\cot(\varphi - \gamma)\tan\theta_A \end{aligned} \tag{7}$$

$$\Delta Q/k_f = \Delta s/r_A \sin\theta_A/\sin(\varphi - \gamma). \tag{8}$$

Now we can start to calculate the whole set-up, beginning with the parameters for the centre analyser

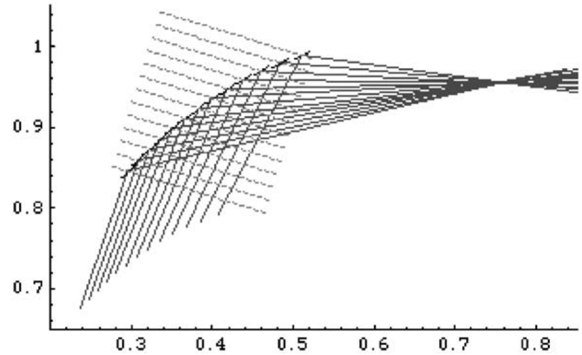

Fig. 2. The calculated flight paths around the analyser array with the focus point on the right. The coordinate system is the same as in Fig. 1 and normalised to $r_A = 1$. Again the dashed lines show the analyser rails.

(φ, θ_A, r_A) and the scan direction γ. Eqs. (7) and (8) give the focus point and the step-width ΔQ. Then we get the angular deviations from Eqs. (1) and (2), the displacement vector $\boldsymbol{v}$ from Eq. (5) and finally ξ and Δx for a given Δy. In the linear approximation the step-width ΔQ will be the same for all analysers. The exact solutions will differ slightly and can be calculated for all values of Δy from Eqs. (5) and (6) using the obtained value for ξ.

As an example for the calculations we have (randomly) chosen a scan direction $\gamma = \psi - 20°$ in a typical scan region of IN12 ($k_i = k_f = 1.8\,\text{Å}^{-1}$, $Q = 2.0\,\text{Å}^{-1}$), where we get $\varphi = 67.5°$ and $\psi = -56.3°$. With the parameters $r_A = 120\,\text{cm}$, $\Delta s = 2.5\,\text{cm}$, $\Delta y = 2.0\,\text{cm}$ and $d_A = 3.355\,\text{Å}$ (graphite) we calculate $r_F = 45.1\,\text{cm}$ and $\Delta Q = -0.033\,\text{Å}^{-1}$. From this we get $\xi = -17.0°$. Fig. 2 shows the corresponding arrangement.

Acknowledgements

This work has been funded by the German Research Ministry BMBF under contract number 05-300-CJB-6. The authors also would like to thank G. Eckold for the fruitful discussions and the sharing of ideas in the development process.

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