NSE preliminary case study for the ESS

B. Farago (ILL mailto:farago@ill.fr)
M. Monkenbusch (IFF, FZ–Jülich mailto:m.monkenbusch@fz-juelich.de)

1. Introduction

The purpose of this report is not a detailed proposition for NSE instrument(s) for ESS but to

- examine the technical feasibility of such instrument(s) on a pulsed source
- identify the requirements for the neutron source which suits best the instrument needs
- estimate gains (losses) compared to existing steady state sources

2. Technical feasibility

We are in a very comfortable situation as IN15, the high resolution NSE instrument at the ILL, has a TOF option which has just supplied the first test results. In short we can already report the conclusion: it is feasible.
First of all NSE needs a polarized neutron beam. At least in the cold neutron wavelength range λ>4Å present supermirror technology (up to 3xθ_{nickel}) supplies the best intensity – polarization conditions. Field tested (MESS Saclay, IN11,IN15 ILL, SPAN BENSC) cavity type transmission polarizers are capable to cover e.g. 4.5-12Å waveband without adjustment. In the same cases the analysers (soller arrangement in reflection) perform equally well. This is essential to be able to profit of the largest possible spectrum on a spallation source.
The echo condition is that the magnetic field integral on both side of the p flipper must be the same. Fortunately this condition is independent of the wavelength. It has been shown (B. Farago , NSE workshop Berlin 2000, to be published) that only the p and p/2 flippers (and not the compensation coils) need the driving DC current to be modulated according the mean wavelength just passing through them. This has two consequences: a) not only the main precession solenoid current but also all the correction elements (fresnels etc) can be kept constant. b) only three time dependent power supplies are needed. Technically their realization is not very demanding as neither the frequency (say 16 Hz) nor the current (0.7-2.1 Amps) is high.
There are no special requirements for the detection chain which would go beyond already existing technology with one exception: detectors capable of handling higher count rates are necessary. However this is not specific to NSE but rather a general point for ESS.
By the time ESS is built we can expect more development on instrument optimisation especially as NSE is a relatively young technique. This however is not specific to the pulsed source.

The most striking property of NSE is it's very high energy resolution, however, experienced in the Fourier domain in terms of the Fourier time t. Besides the task to take advantage of the pulsed source characteristics and use the supplied neutrons as efficient as possible, a NEXT GENERATION NSE should extend the Fourier time limit beyond

the present values. IN15 constructed according to the generic IN11 principle and using long wavelength provides the current maximum (~200ns). As pointed out above the minor modification of ramping flipper currents ONLY (plus appropriate data collection) is sufficient to cope with the pulsed white beam characteristics. Therefore the most promising path to arrive at a beyond-state-of-the-art NSE in terms of resolution and intensity is a still a sophistication of the IN11 design using ramped flippers.
To obtain high efficiency the accepted solid angles of the sample and in particular of the detector should be as large as possible. The solid angle of sample illumination and the fraction of the sample that is "seen" by a detector element depends on the reflection edges of the available supermirrors, a wide gap between spin-up and –down edges immediately increases the available solid angles (especially at shorter wavelength).
The total detecting solid angle depends on the availability of appropriate "Fresnel" coils that correct for the field integral inhomogeneities. Here radial current densities above 100A/mm must be carried by a neutron transparent conductor and must be realized with an accuracy of 0.1% (mechanical position, shaping ...). In an environment around a spallation target station (iron shieldings...) care must be taken that the magnetic fields in the instrument are not corrupted by outer influences as magnetized iron parts etc.. Besides other advantages (see Juelich NSE) compensation of stray fields is mandatory in particular if higher Fourier times shall be obtained that require higher magnetic fields. If all accuracy requirements and conditions on length and solid angel are considered an ambitious but still just realistic upper limit for the Fourier time will be about 1000ns. Even this requires progress on the Fresnels and the main solenoids (+compensation) are better to be made superconducting. However that requires the thorough understanding of the flux exclusion and hysteresis effects of a real superconducting coil. A normal conducting design might still be feasible but will have a electrical power consumption and corresponding cooling requirement approaching 1MW at the highest Fourier times.

3. Source requirements

Neutron scattering is not a new technology. While it can not be excluded that something fundamentally new will be proposed (like NSE was in the seventies) break through can be expected only if there is at least one or two orders of magnitude increase in the output quality or quantity. Similarly to synchrotron vs standard Xray sources, intensity is the fundamental for both (coupled with state of the art instrumentation).
Taking as reference the report by F. Mezei (ESS reference moderator characteristics… 4-12-00) for cold neutrons the "coupled long pulse" source is superior at all wavelength by a factor ˜ 10 above all others in terms of time averaged flux.
We will examine now if its time characteristics are appropriate.
The total length of the NSE instruments (transm. Polarizer + precession coils + analyser) is about 10m. Taking into account the heavy protection of the source we can count on a detector to source flight path L_D˜ 20m.
The estimated pulse width is dt =2msec the repetition rate T_{rep}=60msec.
This leads to usable band width (set by frame overlap)

$$l_{max} - l_{min} = 3.960 \cdot T_{rep} / L_D \approx 12 Å$$

and monochromatization of

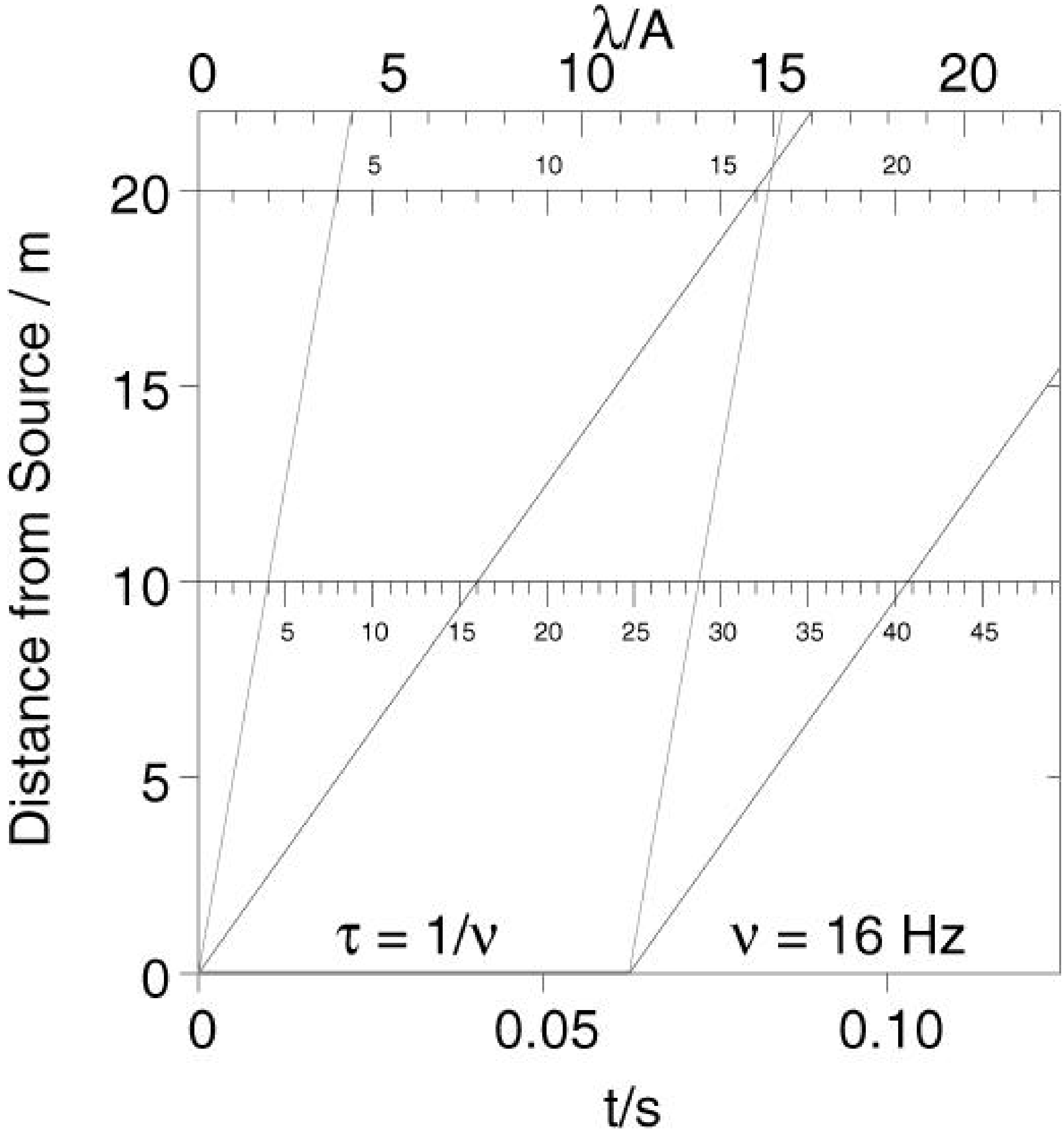
$$dl/l = 3.960 \cdot dt/L_D l \approx 0.4/l$$

Using the shortest wavelength part of the spectrum (say 4-10 Å) our worst monochromatization is already 10%, which is better than the presently usual (15-18%) on NSE instruments. As this extra monochromatization comes for free (no intensity loss) this is a welcome feature in q resolution improvement.

Phasing a frame overlap chopper (needed in any case) somewhere half way between the detector and the source the actually used wavelength band can be selected e.g. 4-16 Å or 12-24 Å.

We conclude that the “coupled long pulse” source is the choice for NSE.

4. Gains, Losses



With the “coupled long pulse” source the time average flux is estimated to be nearly the same as the ILL. This makes comparison very easy. Instead of a 15% FWHM wavelength band we might be able to use 6-12 Å band (repetition rates 32Hz and 16Hz resp.). The comparison becomes more delicate if we question whether ALL this band is useful or not as it will depend on the physical problem. In past years a large fraction of use of IN11 and IN15 was in the SANS range. These problems are especially well suited for the use of all the wavelength. Indeed there
is a double good match: a) for a fixed scattering angle there is a favorable compensation between the λ^{-n} decay of the incoming spectrum and the typical $q^{-m} \sim \lambda^{+m}$ intensity dependence of small angle scattering. b) similarly NSE Fourier time (resolution) increases with the third power of lambda going in pair with the $\exp(-q^{n}t)$ typical (n=2..4) dependence.
Any inverse situation decreases the usefulness of the wide wavelength band. In extremis there might be only one q of interest, in this case the instrument would be equivalent to one at the ILL. (With inferior choice of moderator the instrument will be consequently inferior)
As mentioned above the better wavelength (q) resolution is also on the gain side as avoids complicated second order effects on the measurement.
Sometimes on IN11 a graphite monochromator had to be mounted to improve q resolution. As usually this was necessary for measurements in the high q range(q> 0.3Å-1) it is thinkable to build a wide angle NSE instrument (like SPAN or IN11C) at a larger distance from the source for improved monochromatization. From the equations above it is clear this will restrict the wavelength band (but compensated by large solid angle detector array). There the aim is not to improve on neutron quantity (flux) but on quality (monochromatisation). No good q resolution multidetector NSE instrument exists at present.
On the “lose” side we have to mention inelastic NSE. There seems to be no possibility to implement it at a pulsed source (beside using it as a steady state one).