Some New Instruments Designed To Use The Time Structure Of A Quasi Continuous Spallation Neutron Source

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1. Introduction

The instrumentation on continuous neutron sources has become more and more standard, only few novel instruments have been developed recently, for example the spin echo instrument in Grenoble. The situation is quite different for a quasi continuous source like the spallation neutron source for which a feasibility study is performed in Germany. For our discussion it is not necessary to consider details of the time structure, for this reason we idealize this time structure as one with a periodic sequence of rectangular pulses with a width τ of 0.5 msec, a repetition rate ν of 100 Hz and a peak flux $\hat{\phi}$. With thesedefinitions the mean flux $\bar{\phi}$ is given by $\bar{\phi} = \hat{\phi} \cdot \nu \cdot \tau$. The time structure of such a neutron source offers the possibility to use existing instruments more efficiently and to develop new instruments.

In this paper three instruments are described which have not been built up to now on a neutron source and which are especially well suited to be used on a quasi continuous neutron source. The first instrument described is a time-focusing high resolution time of flight spectrometer which was proposed already in 1967 by H. Maier-Leibnitz /1/, which we call "Bunching Spectrometer". The second example is a high resolution backscattering spectrometer, a modification of the existing backscattering instruments in Jiilich and Grenoble. The third instrument is designed to produce either polarized neutrons or ultra cold neutrons with a new technique, the dynamical polarization of neutrons by neutron magnetic resonance.

I. Bunching Spectrometer

Looking on the space-time diagram, Fig. 1, we see immediately that is is possible to obtain time focusing of different neutron velocities after a flight length L_o, if the different neutrons start at L = 0 with a special time dependence. In any case the slow neutrons have to start earlier than the faster neutrons. With special approximations (the velocity spread Av has to be small compared to the mean velocity v_o) we obtain the bunching condition

$$v(t) = \frac{v_o^2}{L_o} t$$

This linear dependence of the neutron velocity *on* time can be obtained easily by reflecting a neutron beam from a sinusoidally vibrating crystal during the linear part of the sin-function. This is shown in the lower part of Fig. 1.

The intrinsic uncertainty of the time of flight AT is given by

$$A T = \frac{L_o}{0,} \frac{\Delta v}{v_o} + \frac{\Delta L}{L_o}$$

The width of the reflecting curve $\Delta v/v_o$ of a silicon crystal in

back-reflection due to primary extin tion is given by

$$\frac{\Delta v}{v} = \frac{4F}{\pi \, v_c \, \tau_c^2}$$

F: structure factor

v_c: Volume of the unit cell

τ_c: Reciprocal lattice vector

and has a numerical value of $2 \cdot 10^{-5}$ for the (111)-reflex. With this value and an uncertainty AL (thickness of the sample and detector, amplitude of the vibrating crystal) of 6 cm, a length L_o of 60 m and the neutron velocity of 631 m/sec we obtain a pulse length of $12 \cdot 10^{-6}$ sec.

The vibrating amplitude of the crystal is obtained by the equation

$$\frac{dv}{dt} = \frac{v_o^2}{L_o} = a\omega^2 \quad \text{or} \quad a = \frac{v_o^2}{L_o \omega^2}$$

with $\omega = 628$ we obtain a = 1.7 cm.

A schematic picture of this instrument is shown in Fig. 2. Immediately after the shielding of the reactor the neutron beam is deflected by a rotating graphite crystal to the vibrating silicon crystal. The back-reflected neutrons are conducted in a neutron guide tube to the sample. The focussing length L_o from the sample to the detector is dependent on the energy transfer and is shown in Fig. 3.

II. Modified High Resolution Back-scattering Spectrometer

The back-scattering spectrometer is a special version of a triple axis crystal spectrometer with the Bragg-angle of the monochromator and the analyser being 90^o /2/. The energy scan is performed by Doppler moving the monochromator parallel to the reflecting τ_c vector resulting in a change of the incoming energy. If this instrument is used on a quasi continuous source the time averaged counting rate is proportional to the mean flux $\bar{\phi}$. However, the useful neutrons appear in the detector during a time interval which is equal to the pulse length of the source. With the time structure given in the introduction only 5 % of the time neutrons are counted. Here we propose a back-scattering instrument which gives at least ten times more intensity in the time average by utilizing not only 0.5 msec of one period (10 msec) but 5 msec. The principle is as follows:

The Doppler moved monochromator is replaced by ten silicon crystals which have different lattice constants given by the intrinsic reflection width. The relative intrinsic width of the (111)-reflex is $2 \cdot 10^{-5}$. The thermal expansion coefficient of silicon near room temperature is $2.5 \cdot 10^{-6}$. It follows that in order to establish a relative lattice parameter difference of $2 \cdot 10^{-5}$ a temperature difference of 8^o is necessary. In order to be able to measure the different energies of the neutrons separately we have to accomplish that they arrive at the detector at different times. This effect can easily be obtained by imposing to each of the ten different energies a different flight time to the detector. If we want that the reflexes of

the crystals arrive at the detector one after the other and without a time gap between them, the difference of the flight time between two reflexes has to be 0.5 msec. From the equation $L = vT$ we obtain

$$\Delta L = L \frac{\Delta v}{v} + v\Delta T$$

Inserting into this equ. L = 10 m, v = 631 m/sec, $\Delta v/v = 2 \cdot 10^{-5}$ and $\Delta T = 0.5 \cdot 10^{-3}$ sec, we see that the first term can be neglected and we obtain ΔL = 31.5 cm.

A schematic picture of this instrument is shown in Fig. 4. A rotating graphite crystal (frequency 100 Hz, in phase with the source) deflects the neutron beam to the silicon crystals which are adjusted perpendicular to the deflected beam and are separated by a distance of 15.7 cm. The crystals are kept on different temperatures with a temperature difference of 8^{o}. If the crystal which is nearest to the sample has the highest temperature we obtain the time-energy diagram of Fig. 5. Each of the ten rectangular regions represents the reflected energy of the ten silicon crystals. The long horizontal bar represents the reflection curve of the analyser crystal. The counting rate is stored time dependently in a multi channel analyser. In Fig. 5 we expect an elastic line with a line width of $0.5 \cdot 10^{-3}$ sec at the indicated time. An energy shift of the scattered neutrons produces a time shift given by the slope of the diagram in Fig. 4.

$$\frac{\Delta E}{\Delta t} = \frac{2E\Delta v/v}{\Delta t_s}$$

With $\Delta v/v = 2 \cdot 10^{-5}$ and $\Delta t_s = 0.5 \cdot 10^{-3}$ sec we obtain

$$\Delta t = 6.25 \cdot 10^{3} \Delta E$$

Inserting for the energy transfer a value of 10^{-7} eV we obtain a time shift of the line of 0.62 msec, a value which can be measured easily. The fact that we can only measure neutrons half of the available time has the same reason as already described for the existing back-scattering spectrometers /2/. In contrast to these spectrometers the above described instrument profits from the peak flux and not from the time averaged flux of the neutron source.

III. Dynamical Polarization On A Pulsed Neutron Source

Preliminary experiments /3/ have shown that neutron magnetic resonance can be used to produce a completely (not only 50 % but 100 %) polarized neutron beam. If monochromatic neutrons with kinetic energy E enter a magnetic field B_o, the beam is split into two subbeams, one with the spin direction parallel to B_o and the kinetic energy $E + \mu B_o$, the other beam with the spin direction antiparallel to B_o and the kinetic energy $E - \mu B_o$. If the spin directions are reversed within B_o by an oscillating magnetic field B_s perpendicular to B_o, the kinetic energy of both subbeams outside the magnetic field B_o is different by $4 \mu B_o$. An experimental proof of this energy splitting is shown in Fig. 6. This effect can be used to produce a completely polar-

ized neutron beam on a pulsed source /4/. In Fig. 7 a white neutron pulse is "monochromized" after a flight path L according to the relation $\Delta E_{TOF} = h^3 \Delta t / m^2 \lambda^3 L$ (h: Plancks constant, Δt: pulse length). If this resolution is better than the total energy separation ΔE_N of the two spin states after the N-stage neutron magnetic resonance system, the two polarization directions can be turned into the same direction by a spin precession difference of π of the two polarized subbeams in a magnetic field B_p (spin precession region in Fig. 6). This condition is fulfilled for all neutron velocities, when B_p is given by

$$\int_{\frac{L+a}{v(t)}}^{\frac{L+a+l}{v(t)}} B_p(t)dt = \frac{mv^2(t)\pi}{\gamma \Delta E_N}$$

A solution of this equation is given by

$$B_p(t) = \frac{B_p(o)}{t^3}$$

with $B_p(o) = \frac{2m\pi}{\gamma \Delta E_N} \left(\frac{1}{(L+a)^2} - \frac{1}{(L+a+l)^2}\right)^{-\frac{1}{2}}$

With the following numbers

N = 10 $\quad B_o = 2$ T

L = 20 m $\quad B_p(o) = 0.02$ T $\quad l = 1.7$ m

a = 5 m $\quad t = 10$ µsec

we obtain a polarized wavelength interval between 4 Å and 5.3 Å where the last value is determined by frame overlap.

IV. Time of flight correlation spectroscopy

When the correlation spectroscopy was discovered for neutron scattering about ten years ago, many people expected a revolution of the neutron spectroscopy by this in principle very powerful technique. But things were a little more complicated than envisaged at the very beginning. The main disadvantage of this technique was early discovered and is very crudely described here. We consider a very simple frequency spectrum of our sample, consisting of one weak and one strong line. If this frequency spectrum is measured with the correlation technique the two lines of the frequency spectrum produce a structured intensity distribution which is the sum of two structured intensity distributions of the two lines. In the worst case the intensity modulation due to the weak line is lost in the statistical noise of the intensity produced by the strong line. This extremly bad property of the correlation technique can be removed at a quasicontinous source by an additional time of flight separation of the intensities o both lines. This aspect is one of the most promising things of a quasicontinous neutron source and I would not be astonished if a new experimental period would come up with the spallation source, the "Correlation Time".

References

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/2/ B. Alefeld, Kerntechnik 14, 15 (1972)

/3/ B. Alefeld, G. Badurek, H. Rauch, to be published

/4/ G. Badurek, H. Rauch, A. Zeilinger, Z. Physik B 38, 303 (1980)

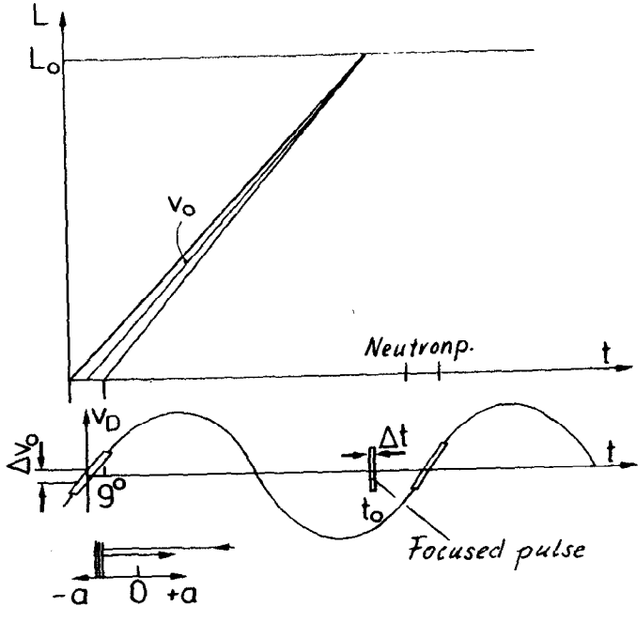

Fig .1 Time-space diagramm and time focusing for the Bunching Spectrometer

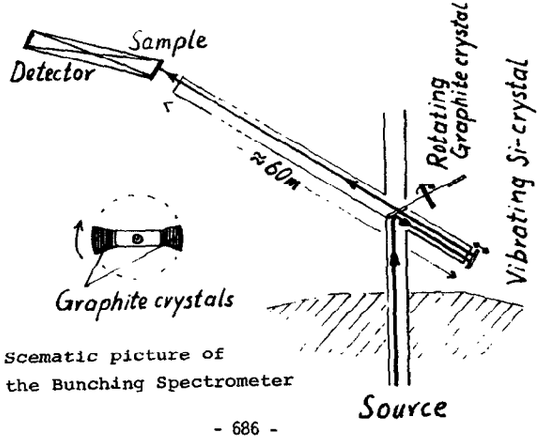

Fig. 2 Scematic picture of the Bunching Spectrometer

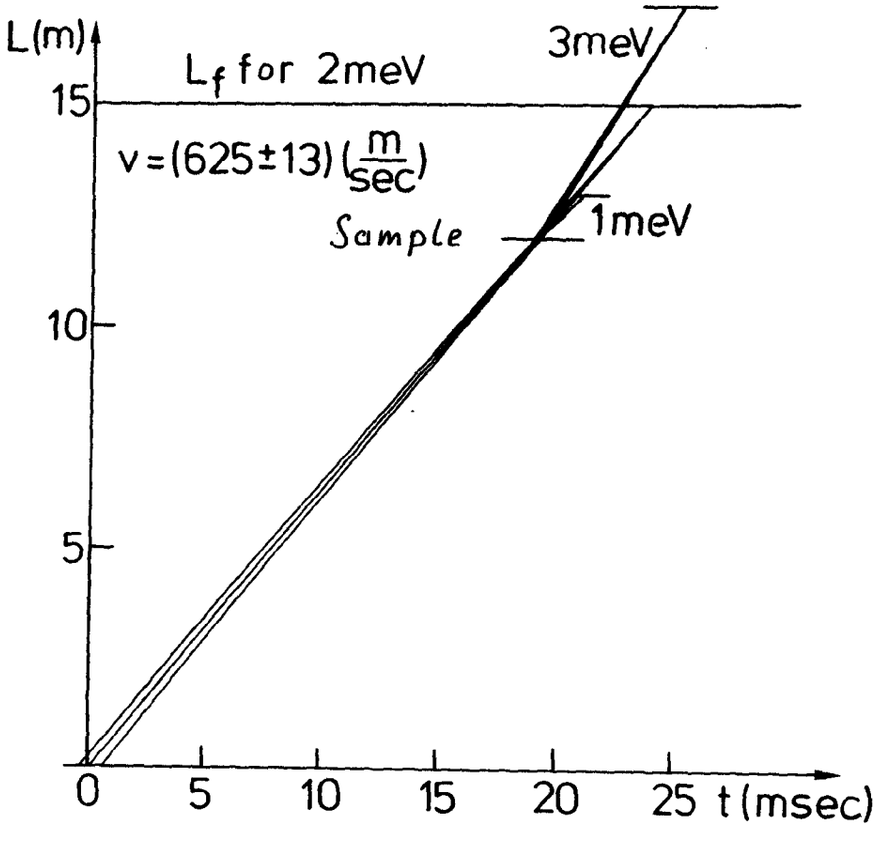

Fig. 3 Time focusing of the Bunching Spectrometer for energy transfers of zero meV, 1meV energy loss and 1meV energy gain.

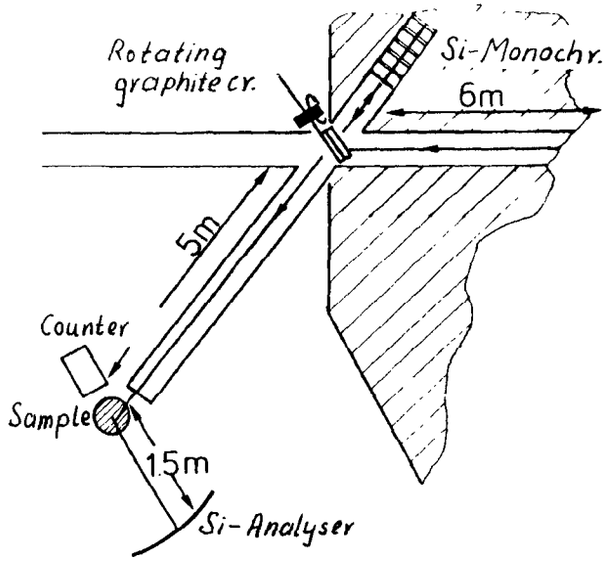

Fig. 4 Modified Backscattering Spectrometer. The distance between the Si-monochromators is 15.7 cm, the temperatur difference between two monochromators is 8° C.

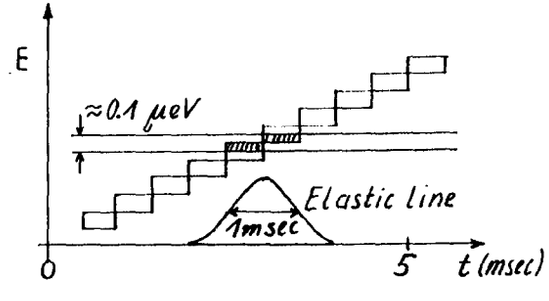

Fig. 5 Energy-time diagramm of the modified Backscattering Spectrometer. The elastic line is shown at the crossing region of the monochromators and the analyser.

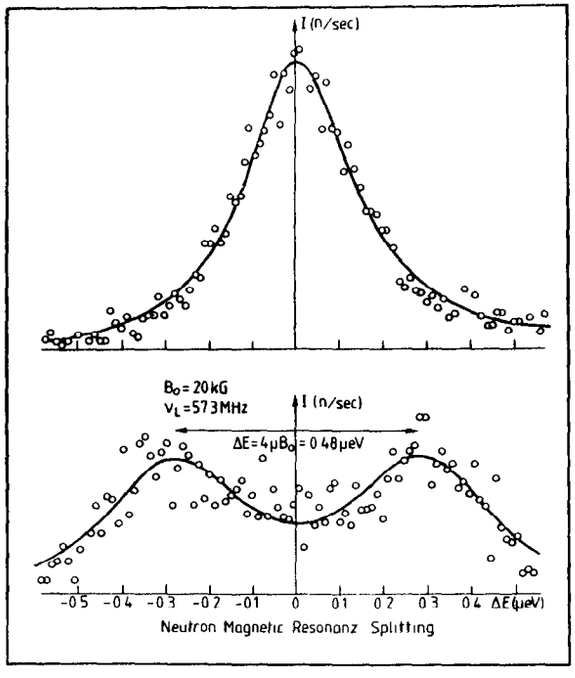

Fig. 6
Neutron magnetic resonance splitting measured with a Backscattering Spectrometer. The upper curve shows the energy resolution (without resonance), the lower curve the energy splitting at resonance.

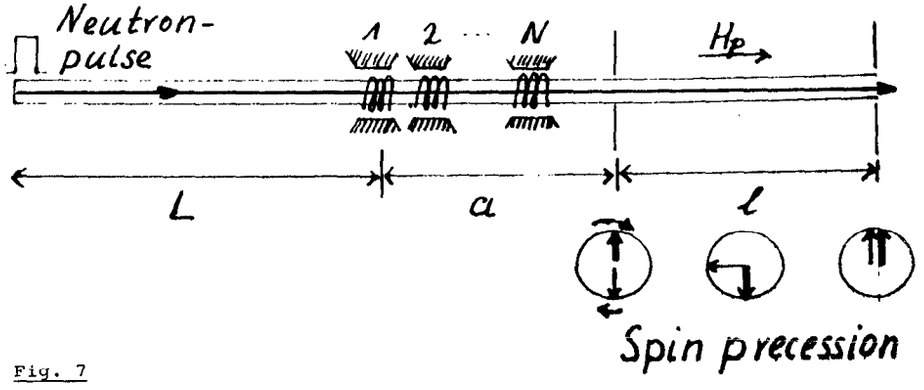

Fig. 7
Scematic picture of an instrument for dynamical neutron polarisation on a pulsed neutron source.