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POLARIZED NEUTRON SPECTROMETER SSN-2 AT MARIA-REACTOR AT ŚWIERK

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Abstract. - The design and construction of a new polarized-neutron spectrometer SSN-2 installed at MARIA-reactor at Świerk are described. Basic instrumental parameters, as well as results of preliminary experiments are also presented.

1. Introduction. - Although over 20 years have passed since the first polarized neutron diffractometer [1] was put into operation, the polarized neutron technique is still under development. The best examples are several recently constructed instruments such as LONGPOL [2], Spin-echo spectrometer [3], PANSI [4] or Three-Dimensional Neutron Polarimeter [5]. New polarizing single-crystals e.g. Fe$_2$Si/Mn/ [6] are being introduced. Also the neutron polarization by mirror reflection from magnetized surfaces [7,8] attracts much attention. The polarizing filters with high polarization efficiencies and transmittances have been tested and in certain cases an effective intensity gain of about 40 times over that for a Co-Fe analyser has been achieved [9]. A review of neutron polarizers can be found in the ref. [10].

The SSN-2 spectrometer is destined for neutron diffraction and spectrometry measurements in the range of neutron wavelengths from 0.7 to 1.4 Å with Co-Fe polarizer. The range of 1.23 to 2.5 Å is accessible with Fe$_{2.96}$Mn$_{0.04}$Si polarizer.

A double crystal monochromator, producing well collimated and pure thermal neutron beam, allows one to use this spectrometer also for small angle scattering experiments. The spectrometer was designed and built for No.5 horizontal channel of the MARIA-reactor at the Institute of Nuclear Research at Świerk. The general layout of the spectrometer is shown in Fig.1.

2. Mechanical construction.

2.1. Double crystal monochromator. - The first monochromator table /see Fig.1/ is fixed directly to the reactor face inside a cave 75 cm deep. The second table, mounted on a carriage, can move along floor rails which are parallel to the reactor channel axis. A large shielding block made of masonite is placed on the same carriage. Depleted uranium and lead blocks acting as beam stoppers are inserted into this shield at the level of the primary beam. The first and the second tables are mechanically coupled by means of two parallel telescopic arms. When the carriage moves, both tables rotate with a half of the speed of the telescopic arms. The tables once adjusted to the Bragg reflection maintain this condition with an accuracy.
better than 1 min. of arc within the whole excursion range of the second table. Each table is housed inside a separate masonite shield with a cover on the top. In addition, the beam path between the tables is also shielded by a sort of two caterpillars constructed of masonite blocks. Inner walls of the table shieldings and the tunnel opening through the caterpillars are covered by a 1 cm thick "boroplast"-material, containing 60% of boron carbide.

The second table is provided with a driving mechanism which allows for a 360° rotation used for fine adjustment of the polarizing crystal. Execution of this movement is possible only after manual activation of an electromagnetic clutch. Otherwise the table shaft remains coupled with the telescopic arm through a 1:2 reduction. The additional rotation of the second table is controlled by means of an optical digitizer with an accuracy of 1 min. of arc.

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2.2. Sample assembly. - It consists of a spectrometer base /Fig.1, pos.10/, a sample table and a sample arm. The spectrometer base is constructed as a carriage moving on four rollers along the floor rails. It can be also shifted perpendicularly to the rails - to set
the table axis in the center of the neutron beam. The rollers are mounted on the eccentric shafts for levelling the base. The sample table /pos.11/ can carry a load up to 300 kg without a noticable deformation or change in the driving power. The table is driven by a d.c. 60V electric motor via a worm-gear coupling. Angular positions are read by an optical digitizer with an accuracy of 1 min. of arc. The sample arm/pos.12/ is fixed to the outer support, concentric with the table /axis C/. Almost in the middle of its length, the arm is supported on two rollers. They are eccentrically mounted in order to make the levelling of the arm possible. A driving system similar to the one for the sample table, can rotate the arm from -5° to +135°.

2.3. Analyzer. - It is possible to analyse both the energy and polarization of the scattered neutrons. The analyzer-sample distance can be varied by 85 cm. The counter shield /pos.15/ fixed to the analyzer arm can rotate about B axis by 360°. Neutron detector and Soller collimator /pos.16/ are housed inside a cylindrical insert which can be pulled out from the shield. After turning the analyzer arm by 180° from its "zero" position, and reversing position of the insert containing the counter and the collimator, the spectrometer can operate as a simple diffractometer while the analyzer crystal maintains its previous orientation.

2.4. Vertical diffractometer. - In polarized neutron diffractometry it is sometimes convenient to measure the intensity distribution in the vertical rather than the horizontal plane. For this purpose our spectrometer was provided with a mechanism which lifts an additional counter shield /pos.18/ in the vertical plane up to 85°. Rotation axis E is then horizontal and passes through the intersection point of the polarized neutron beam axis and the B axis. The Soller collimator with a vertical divergence of 40 min. of arc is set in front of the detector.

3. The control system. - The spectrometer is controlled by LÅRA 305 minicomputer with 4 K memory of 8 byte-words, and CDC-licensed disc /5 Kbytes/. The computer-spectrometer interface is assembled of CAAC units. The main auxiliary equipment consists of an alphanumeric display /monitor screen/, mainly used for monitoring the status of the experiment, an oscilloscope, on which the measured spectra can be observed, and an x-y plotter, a tape reader, a tape puncher, and a line printer.

3.1. Manual operation. - A portable manual operation panel is connected to the main control unit through a long cable. It enables selection and driving with a variable speed of one out of five electric motors, as well as the observation of the corresponding angular position on a digital display.

Two separate panels mounted in a rack are used for the remote operation of all goniometers and adjustment of the proper positions of the monochromator, polarizer, sample and analyzer.

3.2. Automatic control. - The control system enables automatic movement of all spectrometer axes, change of state of neutron spin-flippers, and registration of neutron pulses in three detectors /two monitors and main detector/ during a preset exposure time. This time can also be defined by the number of monitor counts. The change of the spectrometer axes takes place simultaneously and in the optimized way due to special self-learning algorithms for the motor speeds.

In order to run the spectrometer one may either program the required modes in advance on punched tape or type them on the monitor /both possibilities provided by the CORE program/, or use directly
the following programs stored in the disc memory:

1. **XYEQ** - calculating the sequence of the spectrometer positions for any linear scan in the E-q space; these positions are stored in the disc memory;

2. **SUB1** - used for normalization, subtraction and division of the measured spectra;

3. **DISCO** - used for remote control of the spectrometer; the data needed for setting the spectrometer in a given position are taken from the disc memory. The experimental results are stored in the disc memory;

4. **DATA REPORT** - used for simple data handling;

5. **EDVTA** - used for editing and reading programs /the program employs the alphanumeric display/.

The output data may be registered in the disc memory, on the paper tape or on the punched tape. By using the DATA REPORT-program one can visualize either the whole or a part of the measured spectra on the oscilloscope screen. These spectra can be also plotted either on the x-y plotter or on the paper tape in the form of histograms.

The measurements carried out at any desired spectrometer position and any configuration of spin-flippers may be repeated up to 99 times and the results will be stored in the disc memory. The flipper configurations are numbered from 1 to 4 for the off-off, on-off, off-on, and on-on states, respectively. Let \( P_n \) denotes the required repetition number at the \( n \)th flipper configuration, and \( m/n \) denotes repetition number of the sequence of measurements in which the measurements at the \( n \)th flipper configuration would take place \( P_m \) times after \( P_n \) measurements in the \( n \)th configuration of the spin-flippers. If \( S \) denotes the required number of repetition of the whole series of measurements, the sequence of measurements which is executed by the system is best illustrated in Fig.2: first, measurements are carried out \( P_1 \) times at the configuration No.1, and \( P_2 \) times at the configuration No.2. This set of measurements is repeated \( r_1/2 \) times. Next, measurements are performed \( P_3 \) times at the configuration No.3, and \( P_4 \) times at the configuration No.4; this set of measurements is repeated \( r_3/4 \) times. Next, the similar procedure works for the 1st and 3rd configurations, and for the 2nd and 4th configurations. When this cycle is completed, it starts over and over again till a required preset value of \( S \) is exhausted.

An interesting feature of the program is its on-line data handling. In addition to the possibility of printing and punching single data, after a given series of measurements /e.g. \( P_1 \) measurements at 1st position/ the check on internal consistency is made: the arithmetic average of the measured intensities and its standard deviation is calculated. Any point which deviates by more than 3 standard deviations from the average is rejected. If more than half of the measured points must be rejected - the error message is printed. The calculated average and standard deviation are stored in the memory. After repeating a sequence of measurements the required number of times, the weighted average is calculated from the above
average intensities. Similarly, the weighted averages will be calculated after 5 cycles of the measurements.

The background may be similarly treated and subtracted at wish from the effect /DATA REPORT program/. The polarization ratio can next be calculated by the SUDI program.

One may say in conclusion that in spite of small computer memory and its short word-length, the developed system satisfies most of experimental needs.

4. Spectrometer parameters. - The thermal neutron flux measured at a 20 kW power is $2 \cdot 10^{14}$ n cm$^{-2}$s$^{-1}$ at the inner end of channel 5 of the Hanf reactor. The flux measured by activating Au foil set at the first monochromator position is $3.3 \cdot 10^9$ n cm$^{-2}$s$^{-1}$.

The choice of the first monochromator depends on the kind of the second monochromator-polarizer. If Co-Fe crystal is used as a polarizer, the Cu single crystal is set as the primary monochromator. In such a case the accessible range of neutron wavelengths is 0.7 to 1.4 Å. If (iii) reflection from Fe$_{2.96}$Mn$_{0.04}$Si crystal is used for neutron polarization, pyrolytic graphite is the most suitable primary monochromator. With such a combination of crystals one may obtain neutrons in the wavelength range of 1.23 to 2.5 Å.

The check of the basic parameters of the spectrometer has been made with 35x35x3 mm Co-Fe (200) polarizing crystal set in transmission. The 170x50x10 mm Cu crystal was set in reflection. The neutron wavelengths at which polarization and flipping efficiencies have been measured were 0.93, 0.98 and 1.27 Å. The only Soller collimator in the system had a 30° horizontal divergence and was situated in front of the BF$_3$ detector. The fission chamber placed after the first monochromator was used as the monitoring detector.

The vertical magnetic guide-fields are produced by coils made of 1 mm diameter enamelled copper wire. The overall construction is the same as used in ref. [11]. The height of the coils is 8 cm, and their inner walls, parallel to the neutron beam, are 6 cm apart. Each coil consists of eight layers wound on a masonite core. They are fed from DC power supplies of $10^4$ A current stability.

The resonance and Mezei-type flippers [12] were checked. The latter were constructed after suggestion of Williams [9] and turned out to work very well.

4.1. Flipping efficiencies, neutron beam polarization. - In order to check flipping efficiencies of the Mezei-type flippers the geometry was used in which the neutron beam, after passing through the first spin-flipper in front of the sample/, entered the second one, set in front of the analyzer which scattered the beam into the neutron detector. Two different 3 mm thick Co-Fe single-crystal analyzers have been examined. The flipping efficiencies obtained at 0.93 and 1.27 Å were better than 99.9%, while at 0.98 Å they were 99.8%. The value of $P_a P_r$ where $P_r$ is the neutron polarization at the analyzer and $P_a$ is the polarizing efficiency of the analyzer/ is 0.980 (0.001).

The main disadvantage of the flippers used turned out to consists in a large /ca. 15%/ absorption in the copper wire of which the flippers were made. We intend to replace it by an anodized aluminum wire and improve the intensity in this way.

when the first Mezei-type flipper is replaced by the resonance one /dia. 50 mm, length 145 mm, 134 turns of dia. 1 mm copper enamelled wire/ the intensity of the permanent vertical field ca. 10 mT/ the polarization ratio decreases only a little, and the flipper efficiency turns out to be 99.3%.

Independent measurements have been carried out with a Co-Fe analyzer which was only 0.5 mm thick. The polarizing efficiency of this analyzer was known to be better than 99.9%. In fact, the polarization
ratio obtained with this analyzer was as high as 208.4 (2.4).

From the above measurements one gets finally:

- For the first analyzer, $P_1 = 0.995 \pm 0.001$,
- For the second analyzer, $P_2 = 0.984 \pm 0.001$.

The above parameters, i.e. flipper efficiencies and polarizations do not change much with the neutron wavelength, at least in the region studied. A small decrease of $P_1, P_2$ with $\lambda$ is most probably due to the increasing role of an admixture of second-order neutrons. Relatively low polarizing efficiencies of the analyzers are due to the beam depolarization caused by the stray field around the analyzer magnet rather than by the crystals themselves. This may be concluded e.g. from the fact that the polarization ratios obtained are very sensitive to small changes of the distance between the magnetic poles of the magnetizing magnet.

### 4.2. Second-order neutrons

The influence of second-order neutrons on the above results has been checked at 0.93 $\AA$ and 1.27 $\AA$. As one could expect, in the former case the number of second-order neutrons in the beam is so small that it cannot influence significantly the results.

The measurements have been performed with the analyzer set in the Bragg reflection for $\lambda$/$2$. The intensity measured at this position was 0.988% of the intensity measured with the analyzer set in the "normal" (200) reflection for $\lambda$. After correction for the luminosity and reflectivity of the analyzer at these two positions one obtains that the relative amount of the second-order neutrons in the polarized beam is of the order of 0.014%. This influences the high polarization ratios by a negligible amount / $\Delta \alpha/\alpha \sim 0.01$/.

The number of second-order neutrons increases naturally with the neutron wavelength. For $\lambda = 1.27 \AA$ the effect is about three times greater, and the correction for this effect is necessary, although this correction results in a change of $P_1 P_2$ value by less than 0.1%.

### 4.3. Intensity

The intensity measured at $\lambda = 0.93 \AA$ for the polarized beam is about $8 \times 10^5$ c/s. After scattering from 35x35x3 mm Co-Fe analyzer it is about 4000 c/s; the neutron detector radius is 2 cm. This intensity is certainly sufficient for most of magnetic form-factor measurements, and polarization analysis of the beam elastically scattered from a single-crystal sample. It is, however, not sufficient for performing regular inelastic neutron scattering experiments with energy and polarization analysis.

In order to check this point we attempted to observe the magnon scattering from Co-Fe sample /in fact one of the crystals used as analyzers/. The magnetic field on the sample was turned to a horizontal position. It turned out that this field turn did not produce any severe depolarization till the sample was set in between the magnet poles. The polarization ratio measured for the beam passing through the crystal dropped from above 100 to about 50; the polarization ratio measured for the beam scattered vertically as well as horizontally was only about 40. Also the depolarization turned out to depend upon the orientation of the magnet itself with respect to the beam.

The results of magnon measurements with the sample misset by $\phi = \pm 1.5^\circ$ from its Bragg position, and the scattered wavevector along the line joining the origin of the initial neutron wavevector and the end of (200) reciprocal lattice vector, are shown in Fig.3. In both cases only the scattering with spin-flip have been studied. It is clearly seen that the picture obtained is typical for the magnon scattering with a magnon creation /upper part of Fig.3/ or annihilation /lower part/. Unfortunately, the time needed for collecting the experimental points is very long /50 min. per point/.
and it will increase if we measure the scattering at higher missetting angles.

Fig. 3: Magnon scattering from Co-Fe

The intensity of the beam scattered from the analyzer when the sample was not in the beam increases to about 5000 c/s at $\lambda=1.27$ Å. This intensity can still be increased by 50% if the Soller collimator is removed. However, it has been checked that it pays for the elastic Bragg diffraction from single-crystals only. For the scattering from powders the removal of the collimator results in an increase of the peak-widths without any essential increase in the peak-heights. On the other hand, the Soller collimator plays a role in diminishing the background, which was found to be of an order of 1 c/s in the primary beam, and 1 c/hour in the scattered beam.

For $\lambda=1.27$ Å the intensity increases by the factor of 4 when the pyrolytic graphite - Fe$_{2.96}$Mn$_{0.04}$Si monochromator system is used instead of Cu-Co$_{0.96}$Fe$_{0.04}$. However, quite unexpectedly, the polarization obtained was apparently at some angle with respect to the magnetizing field. The origin of this effect is not understood at present and will be a subject of detailed studies.

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