PAST AND PRESENT STATUS OF NEUTRON SCATTERING AT THE RESEARCH REACTOR IN ŘEž

Review paper

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Abstract
In connection with the commemoration of the two important round anniversaries related to our famous scientist G. Placzek, in 2005 there is also just 50th anniversary of starting the construction of the research reactor in the former Czechoslovakia. Naturally, it has opened a new area for scientists in the field of basic and applied neutron research. Namely, after construction of the first diffractometer SPN-100 it resulted in an enourmous expansion of neutron scattering investigations. The present paper describes personal sights of the author back to the history of the neutron scattering research at the Řež´s research reactor as well as to the present status of the activities in this field of investigations.

1. Introduction

Theoretical and experimental research in the field of neutron scattering started after the second world war when first intensive neutron sources – nuclear research reactors were constructed. Soon, however, neutrons have appeared as excellent probes of all kinds of matter. At present, many variations of the scattering process are used which give the technique of neutron scattering enormously wide applicability in studies of structure and properties of the condensed matter. Therefore, at each research reactor or pulsed neutron source there are installed many related experimental devices.

Construction of the research reactor in the former Czechoslovakia started in 1955 and the first chain reaction was realized in it on September 25, 1957. The commissioning of this reactor of the Russian type VVR-S and of the power of 2 MW belongs to the key milestones in the development of research activities in neutron physics (generally), reactor physics and production of radioisotopes in our country. Later on, after two reconstructions the present tank type light water reactor LVR-15 uses the uranium fuel enriched to 36 percent in uranium-235 and can operate at any power up to the licensed ceiling of 10 MW. Thus, the reactor LVR-15, as one of a few of Central Europe neutron sources has become a good basis for basic and applied research. First investigations were focused on pure nuclear and reactor physics. However, after construction of the first diffractometer SPN-100 in 1965, according to the trends in the world, an enormous expansion of investigations in the field of condensed matter physics and neutron optics by neutron scattering have been recorded. Following the year 1965 the following instrumentation basis for neutron scattering has been developed at the reactor LVR-15.

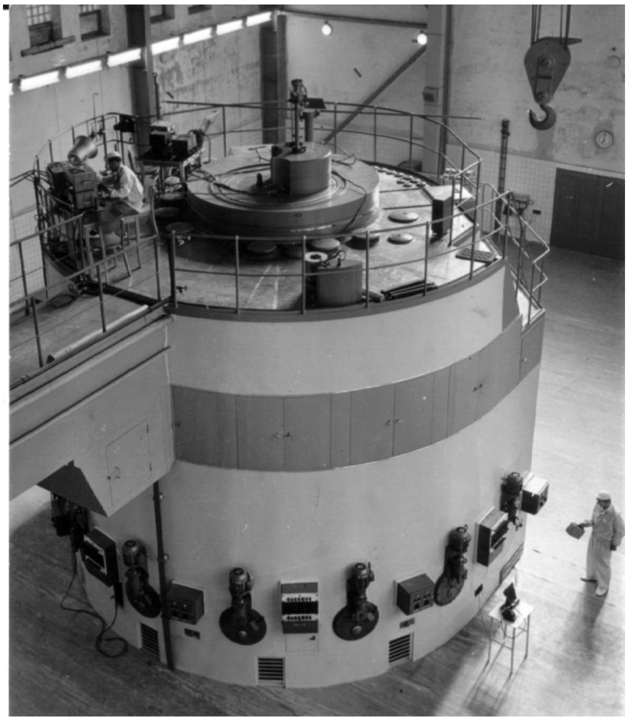

Fig. 1. The reactor VVR-S after commisioning in 1957.

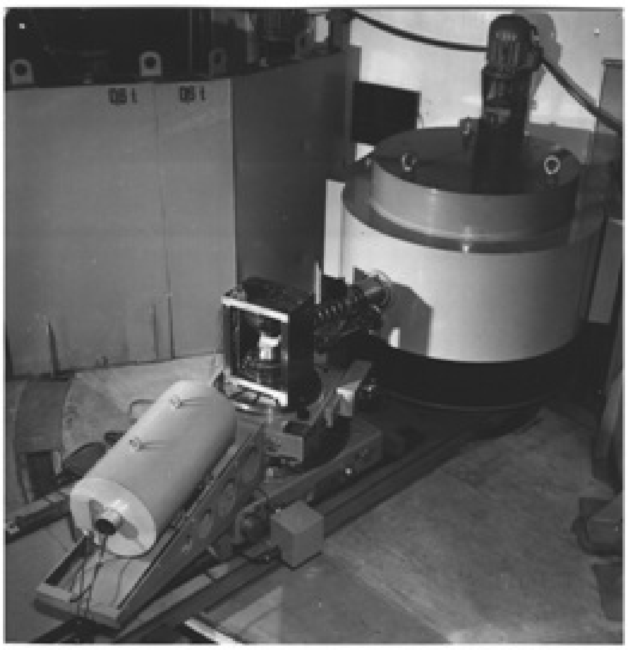

Fig. 2. The first diffractometer SPN-100 after its installation at the reactor VVR-S.

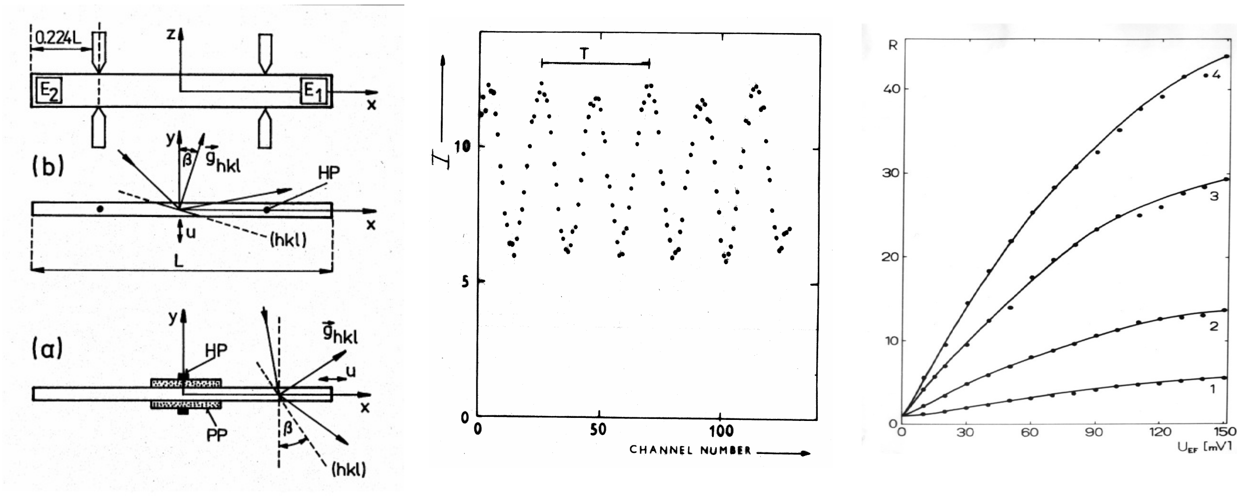

Fig. 3. Schematic sketch of performance for longitudinal crystal vibrations with the holding point at the nodal line in the middle (a) and flexural vibrations with two holding points (b), time modulation of the beam diffracted by longitudinally vibrating quartz single crystal and the relative increase of the integrated reflectivity dependent on the vibration amplitude for different thicknesses of the crystal (3 and 14 mm) and different wavelengths (0.105 and 0.154 nm) [8-11].

1.1 Construction of the multipurpose diffractometer SPN-100

Originally, the scattering device was constructed as a spectrometer of polarized neutrons (SPN) [1]. The instrument was manufactured in the home institute by the group headed by dr. R. Michalec. For its construction top level mechanical components were used and many of them are used unchanged even at the present version (see Fig. 2). It permitted to carry out experiments with polarized as well as unpolarized neutrons at any wavelength in the range of = (0.08 - 0.25) nm. As planned, at the beginning the experiments started with diffraction of polarized neutrons. Namely it was *Diffraction investigations on ferromagnetic perfect crystals* [2, 3]. Later on (beginning of 1967) professor V. Petržílka initiated new research programme *Neutron diffraction by ultrasonically vibrating single crystals* [4]. A large collaboration developed at that time when colleagues from Technical universities in Liberec and CTU Prague joined to the research program. Similar research program was solved in the world only by two groups in USA [5,6] and Australia [7]. From the point of view of publication activity the neutron diffraction group was very productive. In the experiments, different vibration modes on different perfect crystals were used. The following basic effects were investigated on diffraction by vibrating crystals: time modulation of the reflectivity of the vibrating crystal resulting in the time modulation of the diffracted beam, Doppler and aberration effects, shift of the phase of the modulated beam related to the asymmetric diffraction geometry and reflectivity properties of different perfect crystals vibrating on different modes. All these phenomena were studied in a wide range of frequencies 1-5000 kHz and followed by a theoretical description and explanation of the effects (see Fig. 3). Thanks to many excellent results [4,8-18] and returns in the scientific community, Czech pioneers in neutron scattering V. Petržílka, R. Michalec and B. Chalupa were in 1972 awarded by the State Prize.

1.2 Purchase of the three axis spectrometer TKSN-400

Soon, after expansion of the research activities of a rather large experimental team on the diffractometer SPN-100, requirements for an additional experimental beam time have appeared. Thanks to Czechoslovak Commission for Atomic Energy a new spectrometer TKSN-400 was bought in Poland for the Faculty of Mathematics and Physics (FMP) of the Charles University (see Fig. 4) where neutron diffraction group in Řež had about 50 % beam time [19]. The spectrometer in the performance of the two axis diffractometer was in the following several years used also by the Department of Metals of FMP for neutron diffraction studies of structure a magnetic properties of uranium compounds and INRNE Sofia for structure studies of amorphous Te-glasses. Possibility to use three axes of the instrument enabled us to expand the range of investigations and to carry out high-resolution experiments in combination with a premonochromator [20, 21]. Such experiments permitted us to study Doppler and aberration effects in

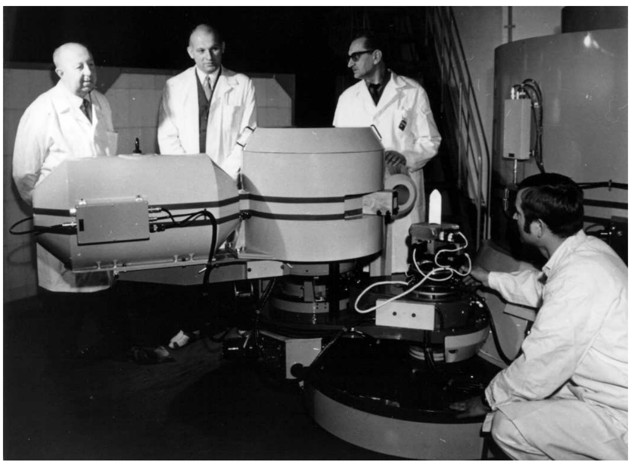

Fig. 4. Three axis spectrometer TKSN-400 bought in 1971. Professor V. Petržílka (left) two Polish technicians and dr. R. Michalec.

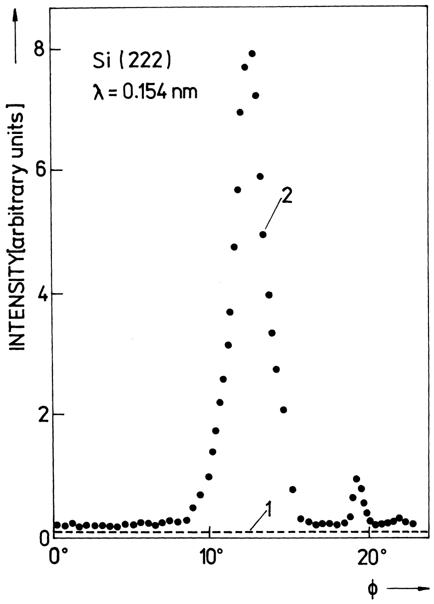

Fig. 5. Multiple reflection effect simulating the forbidden Si(222) reflection. The intensity-azimut dependence for (a) the non-vibrating single crystal and (b) the flexurally vibrating crystal.

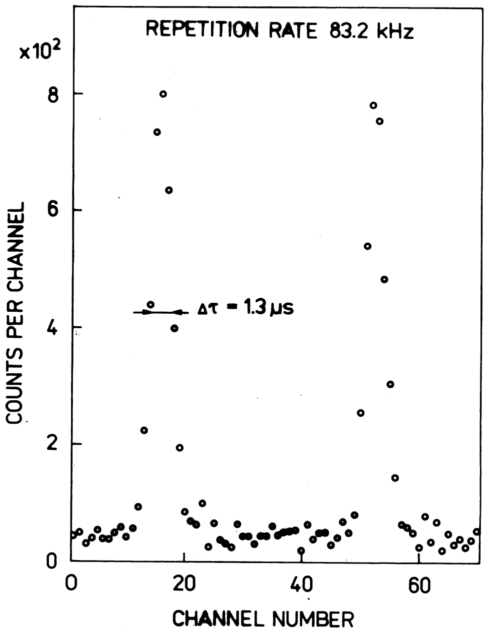

Fig. 6. Time-of-flight spectrum of monochromatic neutrons diffracted by the longitudinally vibrating Si.crystal in which a double hkl/hkl reflection was realized [37].

more detail [22, 23], to study phenomena related to diffraction by two synchronously vibrating crystals [24], to study multiple reflection effects excited by ultrasonic vibrations [25-29], to image the vibration modes by neutron diffraction topography [30-33], to study some dynamical effects of anomalous absorption and "jumps" between the dispersive surfaces related to diffraction by (generally) elastically deformed perfect single crystals. Correspondingly, an attention was paid to possible applications of vibrating crystals [33-35]. As to the fast neutron choppers based on vibrating crystals [24, 36, 37], the repetition rate (f = 2-80 kHz) and the pulse width ($FWHM$ = 1-100 μs), these parameters have not been overcome. Similarly, contrary to our case, in a few cases only weak multiple reflections (often called as Renninger effect) were observed before [38, 39]. Neutron topography experiments [30-33] also can be considered pioneering. In the eighties a new program of diffraction studies by elastically bent perfect crystals started and the research program with vibrating single crystals was slowly damped when finishing by review papers [40, 41]. Later on, in this field only few experiments related to verification of some predictions of the dynamical theory were carried out [42-45]. Starting 1988, the responsibility for the instrument TKSN-400 was assigned to NPI CAS.

1.3 Construction of the dedicated high-resolution diffractometer DN-2 for small-angle neutron scattering (SANS)

On the basis of the first experience with Bragg diffraction optics using cylindrically bent perfect crystals [21,46-49], new type of SANS experiments were initiated on the double crystal diffractometer SPN-100. New methodological investigations in this field [50-53] finally resulted in a design and construction of an original high-resolution dou-

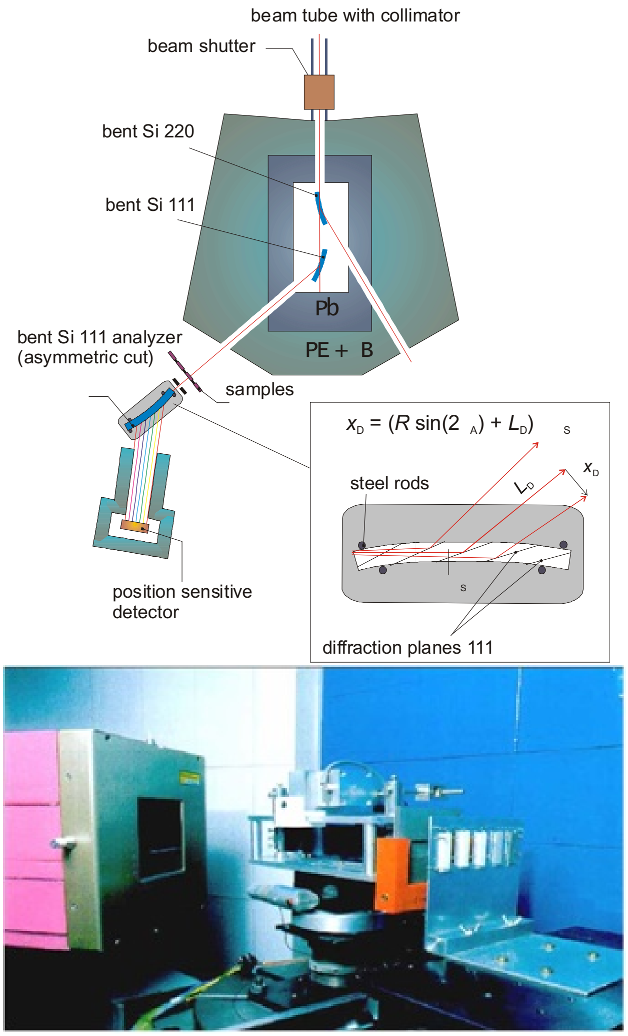

Fig. 7. Schematic diagram of the high resolution double-bent-crystal SANS diffractometer with the fully asymmetric diffraction geometry of the analyzer crystal in combination with a position sensitive detector and the photo of the sample and analyzer part.

ble-bent-crystal SANS diffractometer [55, 56]. Its resolution and the range of the momentum transfer just cover the gap inaccessible by the conventional collimator systems from the one side and the ultrahigh resolution Bonse-Hart diffractometers from the other side. The properties of the diffractometer DN-2 were gradually improved [57] when reaching the final performance also used at present [58]. It should be pointed out that the SANS diffractometr of this type was really the first and in a few years another one has been constructed in HMI Berlin [59]. Last time, the colleagues in PINSTECH (Pakistan) and JAERI Tokai (Japan) have been considering building SANS diffractometers on the same principle. In comparison with conventional SANS instruments our diffractometer with its resolution is very useful for the studies of inhomogeneities of the dimension of 10 nm – 1 m. Thus this technique finds the most of the applications in the materials research e.g. for the study of morphology of large precipitates in superalloys or porosity of ceramics [60-63].

1.4 Construction of the neutron interferometer

The complete apparatus for neutron interferometry including the interferometer crystal of the type LLL (Laue-Laue-Laue) was developed in NPI in 1986-1987 [64]. However, in 1987 the reactor VVR-S was shut down for a refurbishment and the research activities of the neutron diffraction groups were moved to JINR in Dubna, where the NPI group built at the pulsed neutron source IBR-2 the double axis diffractometer DIFRAN. The research program was oriented on studies of dynamical diffraction by elastically deformed crystals [65] and neutron interferometry [66, 67] in collaboration with NPI Gatchina and Atominstitut Vienna, where the neutron interferometry started and has been developed [68, 69]. Thus, for the first time the neutron interferograms were observed by the time-of-flight method. After the refurbishment of the reactor VVR-S (since then LVR-15) a new interferometric apparatus was built and introduced into operation [70]. Even though that neutron interferometer works on the basis of dynamical neutron diffraction by perfect single crystals, at present it is mostly used in the field of fundamental physics, in studies of interactions of neutrons with other particles (as e.g. measurements of neutron scattering lengths [71-74]) and for verification of predictions of quantum mechanics. As in the case of neutron interferometer there is an interference of matter waves, the related apparatus serves as a unique tool for demonstration of quantum mechanical effects on the macroscopical level [75, 76]. We have succeeded to realize a proposal of nondispersive sample arrangement in neutron interferometer [77] and to improve the sensitivity of the method by two orders of magnitude [78-80].

Fig. 8. The view of the three crystal interferometer of the type LLL with the phase shifter PS and the sample S arranged for the nondispersive measurement.

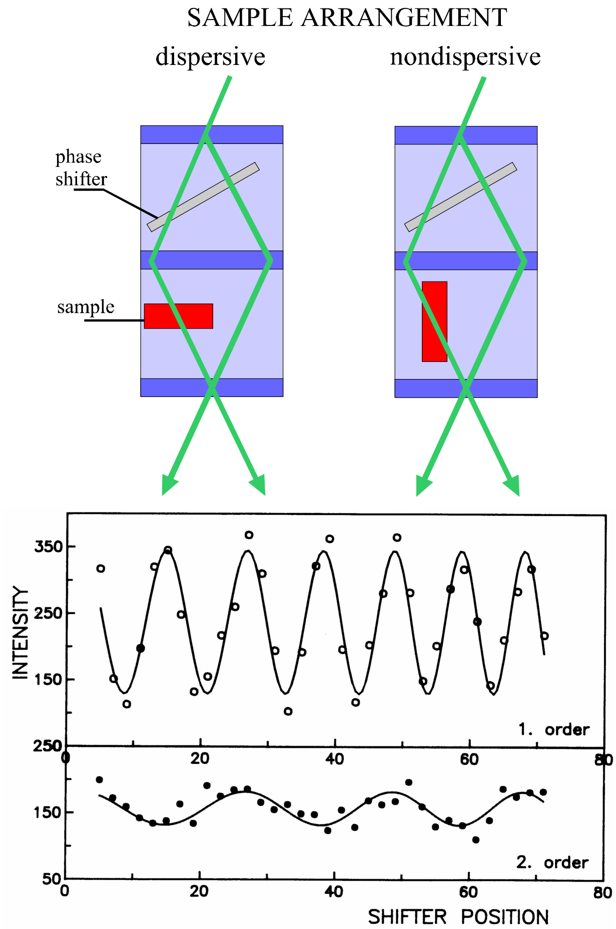

Fig. 9. Schematic diagram of the dispersive and nondispersive sample arrangement and the interference patterns observed in the O-beam of the interferometer simultaneously in the first-(220) and second-order (440) reflection by the TOF method at the pulsed neutron source.

1.5 Installation of the texture diffractometer TEXDIF

Even though that the refurbishment of the research reactor VVR in ZfK Rossendorf (which was of the same type as that in Řež) was successfully carried out, the German authorities decided in 1991 once and for all to deactivate it. Then, the German neutron diffraction group which was world wide known in the field of the texture analysis by neutron diffraction, decided to reinstall their diffractometer at the reactor LVR-15 in Řež (see Fig. 10) [81]. Diffractometer was for many years used namely by TU Freiberg as well as by NPI [82, 83]. At present an extensive modification of the dif-fractometer is carried out with the goal of obtaining a medium resolution powder diffractometer equipped with a modern multidetector system.

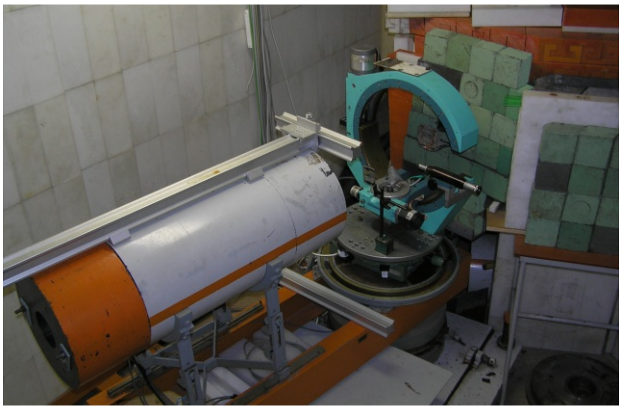

Fig. 10. Diffractometer for texture measurements moved from ZfK Rossendorf to NPI.

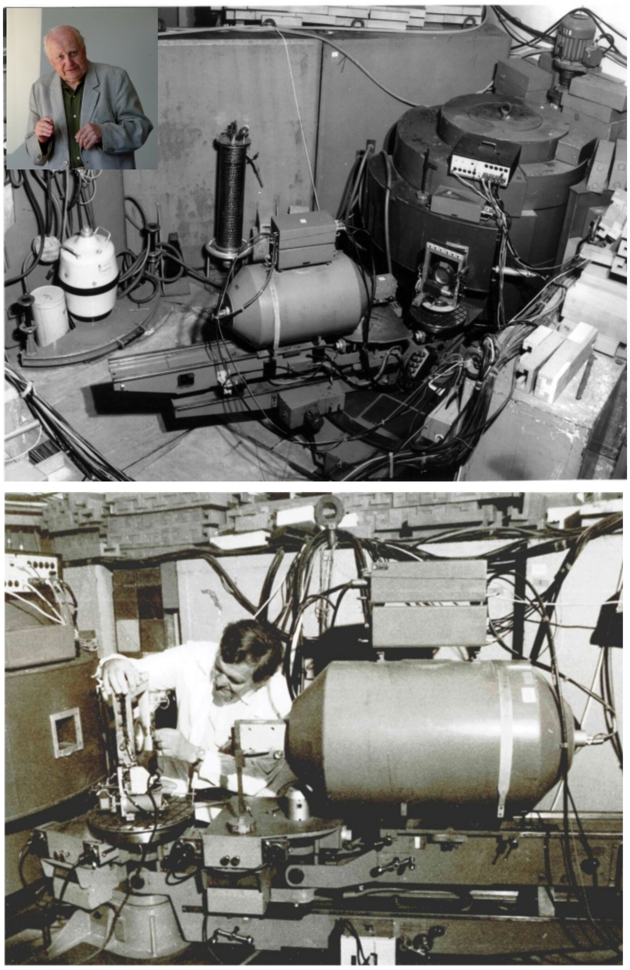

Fig. 11. Powder diffractometer KSN-2 after its installation at the reactor beam hole in 1967. Prof. Č. Šimáně (in the upper part) and ing. S. Vratislav (in th elower part).

1.6 Powder diffractometer KSN-2 of the FNSPE of CTU Prague

The design of the neutron diffractometer KSN-2 was started in the year 1965 on the Faculty of Nuclear Sciences and Physical Engineering CTU in Prague. This diffraction device was installed in 1967 year nearby the second horizontal channel of the research reactor as a second neutron scattering device and at the same year was taken into operation (see Fig. 11). The diffractometer has been used for structure studies, magnetic ordering investigations and quantitative texture measurements. Among the first experiments on the KSN-2 diffractometer belonged the neutron diffraction investigation of the temperature dependence of the distribution of cations in $MnFe_2O_4$ [84]. The neutron diffraction measurements of integrated intensities on quenched single crystals and the measurements of powder diffraction patterns at elevated temperatures were routinely carried out. On the basis of these results, the degree of inversion in quenched samples of $MnFe_2O_4$ was determined in temperature interval from 600 K to 900 K and the reversibility of the temperature changes of the degree of inversion was confirmed.

Neutron powder structure analysis has appeared as an efficient method for investigation of the magnetic ordering and determination of positions of light elements in crystals. The limiting factor for applying the powder method is the resolution and luminosity of the diffractometer. In the case of magnetic structure determination, good resolution is required, especially, in the lower scattering angle part of the neutron diffraction pattern where magnetic lines are observed. On the other hand, for determination of chemical structures a higher resolution is required at larger scattering angles where the frequency of occurrence of nuclear diffraction lines is increasing. From this point of view, new possibilities have appeared after the reconstruction of the VVR-S reactor in 1979 when the thermal neutron flux substantially increased which fact permitted us to improve the instrument resolution. Secondly, powerful Rietveld structure refinement methods for elaboration of the obtained data were introduced. Finally, the neutron optic system of the KSN-2 diffractometer was optimized and the new diffractometer performance could be competitive on the European level [85].

2. Recent research programmes

2.1 Neutron diffraction by elastically deformed perfect crystals

In seventies, professor Meier-Leibnitz initiated in ILL Grenoble the program of Bragg diffraction optics by cylindrically and spherically bent crystal slabs for their possible use in neutron diffractometry and spectrometry. However, these studies resulted only in an employment of focusing mosaic crystals as monochromators and analyzers. Later on, after clarifying and solving some details and problems (e.g. precise calculation of the peak and integral reflectivity [47, 48, 86], optimization of the thickness and the curvature of the crystal [48], possibility of an advantageous use of asymmetric diffraction geometry [87-90]) we have succeeded in the eighties to excite the attention to the program of Bragg diffraction optics in many European laboratories. Since then, advantages of focusing monochromators/analyzers with respect to the mosaic counterparts have been demonstrated in many cases, namely, in particular scattering performances where a higher resolution is required [91-94]. On the basis of the earlier results and experience, a new extinction model was proposed [95] and applied for interpretation of extinction effects [96, 97]. A permanent attention has been paid to the development and tests of new unconventional neutron optical elements (focusing monochro-mators and analyzers) on the basis of cylindrically bent perfect crystals [98-111]. Recently, these methodological studies have been concentrated on the development of high-resolution neutron optical elements, continuation in promising studies of strong multiple reflections realized either in one crystal (Renninger effects) [112-115] or by means of two independent crystals [116, 117] (see Fig. 12). Of course, that several of the newly developed focusing monochromators have been already employed on the diffractometers at the reactor LVR-15 [118-123] as well as abroad [105, 109, 124-125]. In this case it should be mentioned that few pioneering tests of the use of bent crystal slabs in TOF diffractometry and spectrometry were also carried out [111, 126-128].

It is clear that an attention has been permanently paid to the related theory and interpretation of the experimental results [41, 47, 48, 86, 95, 118, 129] and many of them have been oft cited. Furthermore, in the nineties new computer program RESTRAX for *Monte Carlo Simulations of Resolution Functions and Scan Profiles for Neutron Three-Axis Spectrometers* was developed in NPI in collaboration with ILL Grenoble [120-131]. It has been permanently improved [132, 133] and at present it is one of a few programs used in European neutron laboratories [134-138].

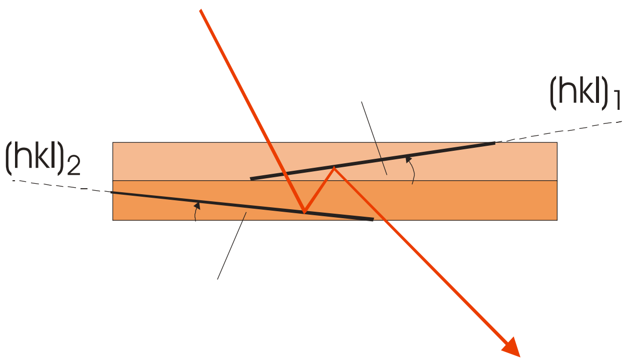

Fig. 12. Dispersive sandwich monochromator consisting of two bent perfect Si- slabs of different cut [128].

2.2 Small-angle neutron scattering (SANS)

Small-angle scattering of X-rays or neutrons is a method which uses elastic scattering in the low-angle range (when compared to a standard Bragg diffraction) for characterization of inhomogeneities of size scale from about 1 nm to 10 m (pores, clusters, precipitates, particles in solutions etc.) [139]. It provides information about their size distribution, volume fractions, shape and anisotropy. Due to the low attenuation of neutrons in most materials SANS is really bulk investigating technique because it can study samples of volume 0.1-1 cm^3. Along with its use in other fields, there is a broad range of applications of SANS in the materials science. In our case in NPI, SANS is used mainly for:

- studies of cavities formed during superplastic deformation in superplastic ceramics which have a significant influence on the mechanical and thermal properties of the final product [140, 141] (see Fig. 13),
- studies of microstructure of Ni-based two phase superalloys characterized by the presence of ’ precipitates of large dimensions embedded in a solid phase matrix when their morphology affects strengthening mechanism even at high temperatures [61, 142-144],
- studies of porosity of plasma sprayed materials which are characterized by a wide spectrum of pores from 10 nm up to 1 m and their evolution and changes brought about by a thermal treatment [145-147].

Permanent attention is paid to the development of the related software for elaboration of the obtained experimental SANS data [146, 148-150].

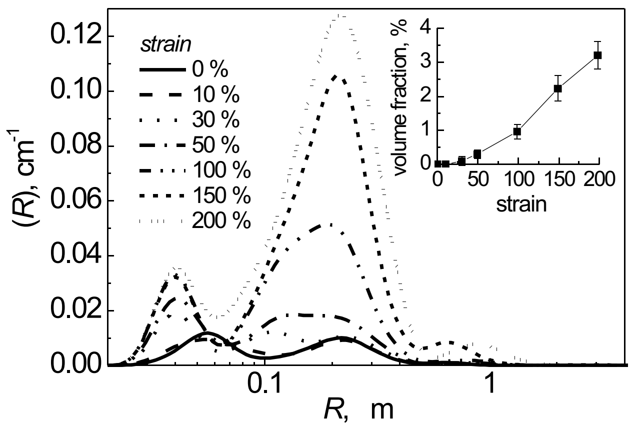

Fig. 13. Size distributions and integrated volume fractions of pores created in the course of super-plastic deformation of Y-TZP ceramics, as results from double-crystal SANS measurements [140].

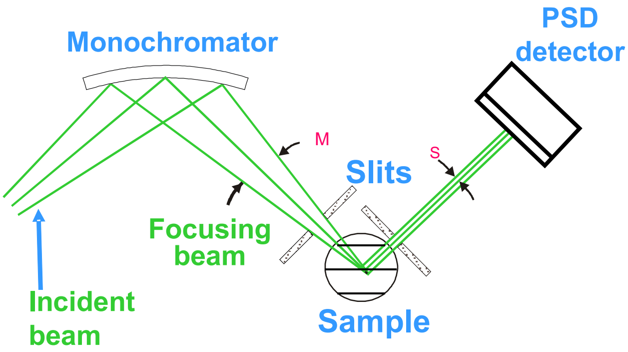

Fig. 14. Sketch of the focusing performance of the diffractometer dedicated to residual strain scanning [119].

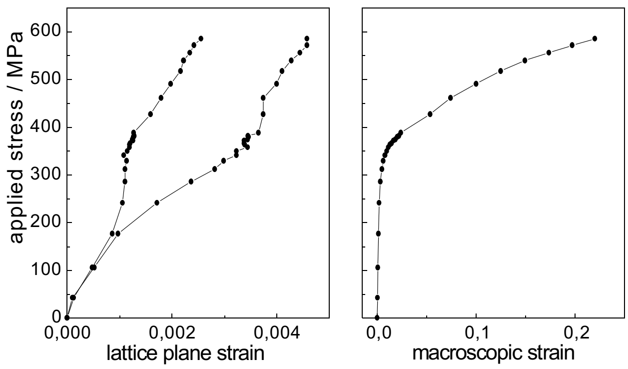

Fig. 15. Stress-strain dependences of related to the individual phases -111 and -110 of a duplex steel obtained from the diffraction experiment (left) as compared with the mechanical one (right).

2.3 Strain/stress studies in polycrystalline materials by neutron diffraction

In 1991, new experiments in the field of powder diffractometry were started, where unconventional high resolution three axis diffractometer performance (with a focusing monochromator and focusing analyzer) was used [141, 152]. This unconventional use of neutron optics brought new results of a methodological character. It has opened possibility to carry out high-resolution measurements of a relative change of the lattice spacing (brought about by elastic deformation) with the accuracy of 10^{-4} as well as to study microdeformations from the diffraction profile analysis. After testing several alternatives [118, 120, 153, 154], the most effective one shown schematically in Fig. 14 is used at the dedicated diffractometers SPN-100 and TKSN-400. Moreover, the diffractometers are equipped with a unique tension/compression rig combined with a heating system. All this permitted to start a successful research program of macro- and microstrain/stress studies in polycrystalline materials in collaboration with many institutions in the Czech Republic and abroad. In the last years the neutron diffraction group has carried out many experimental studies in the field of basic material research by measurements of lattice deformations brought about by a technological process or by an external termo-mechanical load. They have been related namely to studies of deformation properties ultra-high strength nanocrystalline steels, interstitial free steels, ultra-low carbon steels, two phase austenitic-ferritic steels [155, 156] (see Fig. 15) and components of two-part single-crystal composites on the basis of Al_2O_3 [157, 158]. Another group of experiments represent *in-situ* diffraction studies of martensitic transformation taking place in thermo-mechanically loaded shape memory alloys (SMA) [159-161] and the studies of functionally graded Al_2O_3/Y-ZrO_2 ceramics. Different materials based on the alloys of NiTi, Cu (CuAlMnZn) and Fe (FeMnSi) were examined in the frame of a large cooperation. Recently, a progress has also been achieved in a development of computer programs for evaluation of microstructure parameters and the interpretation of results obtained from the diffraction experiments [159, 162].

2.4 Texture measurements of polycrystalline materials

Anisotropy of physical and mechanical properties of polycrystalline materials is strongly dependent on anisotropy of distribution of grain orientation (texture) with respect to a chosen coordinate system. Consequently, the aim of the texture studies is to find a relationship between the texture and macroscopic properties of the investigated material as well as understanding the mechanism of formation of textures and their transformation by means of suitable models. When we limit only on the research activities of NPI in this field, several measurements were carried out in cooperation with U.S. Steel plc., Košice on texture studies of cold rolled plates [82] (see Fig. 16). Recently, a new method of *in-situ* texture measurements of shape memory alloys during a combined termo-mechanical load [83] (employing a small tension/compression rig) has been introduced. As has been already pointed out in §1.5, a complete reconstruction of this measurement device with the aim to

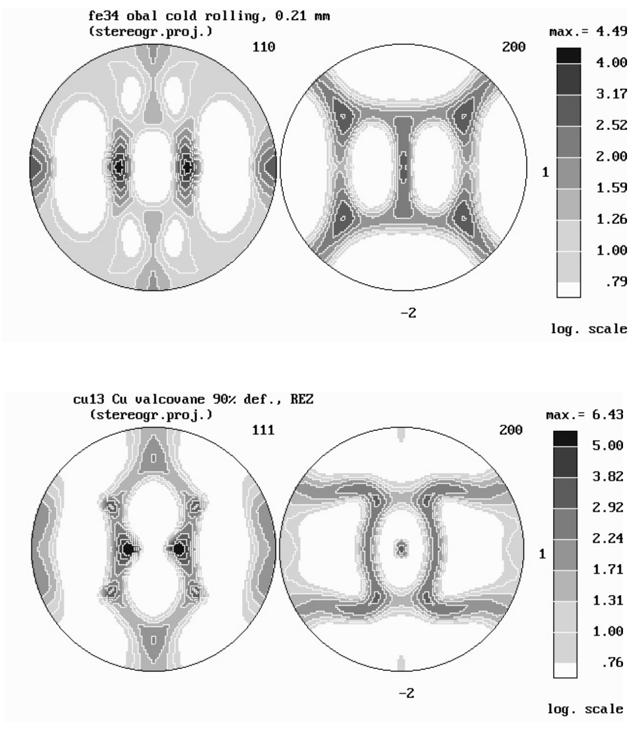

Fig. 16. An example of the pole figures of a tin plate steel (a) and a cold rolled Cu with 90% reduction [82].

build a medium resolution powder diffractometer is planned. It permits the group to expand research activities considerably.

2.5 Powder diffractometry at the FNSPE of CTU Prague

Long experience of the research team in the neutron powder diffraction method for the structure determinations has played an important role for the success of the research activities. The results concerning the mixed-valence systems with copper or other transition-metal ions and dehydrated zeolites were published previously and have received very positive responses. In particular, the neutron diffraction studies of faujasites [163] dealing with the location of protons have been frequently referred and have been regarded as pioneering in the field of the structural solid-state chemistry [164].

The double-axis powder diffractometer KSN-2 [165], is dedicated instrument to the structure and texture experiments on polycrystalline specimens. It is equipped with auxiliary devices, e.g. temperature controlled cryogenic apparatus and heater furnace (up 1000 K), texture goniometer TG-1, magnets. This diffractometer offers good intensity with the the neutron wavelength in the range from 0.095 to 0.141 nm. The recorded diffraction patterns are treated by means of modern analysis PC software resulting in determination of complete structural parameters. The Department of Solid State Engineering of FNSPE CTU has realized the research program mainly in cooperation with the Department of Magnetism and Superconductors of the Institute of Physics, the Department of Surfaces of the Institute of Physical Chemistry and the Department of Neutron Physics of NPI in the Czech Republic and with the Frank Laboratotry of Neutron Physics (FLNP) of JINR in Dubna (Russia). The Department of Solid State Engineering has become an important education centre for graduate and undergraduate students in the field of neutron scattering. In the last years the research program has been mainly focused on:

- Zeolites and related microporous materials, which have common and diverse applications. They are used as catalysts to produce gasoline and pharmaceuticals, for medical and industrial purposes or they are employed to separate N_2, O_2 and other gases. Permanent interest in the structure investigation of zeolites (mainly of the synthetic origin) is stimulated by their potential practical use in the chemical technology [163, 164, 166]. The powder neutron diffraction method participates in the identification and location of the catalytic active sites – cations, protons or other chemisorbed groups. Such data are extremely important for the better understanding of catalytic processes. Structure refinement of the zeolitic materials is applied at present namely in the following directions: the determination of the structure of new generation of zeolites, an estimation of the location of cations and/or protons which act as catalytic active sites and structure refinement of adsorbate/adsorbent systems with the aim to locate positions of adsorbed molecules or of their chemisorbed fragments.
- Complete structural analysis of the ammonium fluoroperovskites $(NH_4)_x M_{(1-x)} F_3$ and ammonium halides $(NH_4)_x M_{(1-x)}$ I (M= 3d or 4d metal) systems [167,168]. The experiments deal with the series samples having different composition x at different temperatures. Investigations of elastic neutron scattering on polycrystalline microsamples under high pressure in diamond and saphire anvils cells have been carried out on the DN-12 diffractometer at IBR-2 pulsed reactor in Dubna.
- The diffraction experiments on different perovskite systems (in collaboration with the Institute of Physics of CAS) [169-169]. Recently, the problem of structural modulation of superconducting layered cuprates on the basis of bismuth which is caused by excessive oxygen in these compounds was successfully studied. The neutronographic results yield unique information about the number and the location of these extra oxygen ions in the BiO layers [170, 172]. The investigations of the $La_{1-x}A_xMnO_3$ perovskites [173-175] with the mixed Mn^{3+}/Mn^{4+} valence as well as the studies of the structure parameters and magnetic ordering of high-temperature superconductor materials (such as $Y_{1-x}Ca_xMnO_3$ at different temperatures and for different content x) are in progress.

3. Collaborations

In seventies, the domestic collaboration of NPI CAS with the Faculty of Mechanical Engineering of CTU, Faculty of Electrical Engineering of CTU and Faculty of Mechanical Engineering in Liberec was concentrated on the realization of the research program *Neutron diffraction by vibrating single crystals*. The foreign collaboration was oriented particularly on JINR Dubna in the frame of the program of studies of *neutron-electron* interactions [65, 176-180]. In eighties, the collaboration with ZfK Rossendorf in the field of Bragg diffraction optics started [181,182]. Namely, it was related to the first tests of the Czech neutron interferometer and the new SANS technique [50, 52, 64, 65]. In the eighties, the diffractometer TKSN-400 was used also by the colleagues from INRNE Sofia for structure studies of amorphous Tellurite glasses [183-185]. At the end of eighties, collaboration started with the University in Ancona in the field of material research [186-190], collaboration with PTB Braunschweig in the field of Bragg diffraction optics [54, 80, 91, 97-103, 108, 112-115] and also with ILL Grenoble [43, 95-97]. In the nineties several new collaborations were linked-up with the Faculty of Mechanical Engineering CTU, Institute of Plasma Physics CAS and Institute of Physics of CAS in the Czech Republic [159-161,170] and the very intensive foreign collaborations have been developed with HMI Berlin, TU Košice (in microstructure studies by SANS), Ibaraki University Hitachi (in strain/stress studies in polycrystalline materials) [140,141, 155, 156], KURRI Kumatori, JAERI Tokai, ILL Grenoble and KAERI Daejon (in focusing neutron monochromators and analyzers and Monte Carlo simulations) [104, 105, 109, 111, 125, 127, 128, 130-132, 157] and JINR Dubna [167, 168, 172, 173].

4. Conclusion

At present, there are installed six neutron scattering devices at the horizontal beam channels of the reactor LVR-15. Besides the neutron optics, the research program carried out at the diffractometers is mostly focused on the material research. The results obtained at the scattering instruments installed at the reactor LVR-15 have been used in about 15 PhD-theses and 2 DrSc-theses. Detailed information about the related instrumentation, research activities, collaborations and publication outputs can be found on the websites http://omega.ujf.cas.cz and

http://147.32.5.30/DesktopDefault.aspx?ModuleId=522 corresponding to NPI CAS and FNSPE CTU, respectively. Since 1991, the research activities in thermal neutron scattering at the reactor LVR-15 have been supported by several grant projects and at present they are namely AV0Z10480505, MSM2672244501, MSM6840770021 and GA-CR 202/06/0601.

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