DESIGN AND SET-UP OF THE NEUTRON GUIDES AT FRM-II

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1. Introduction

Neutron guides are nowadays one of the most important devices for neutron beam handling at classical research reactors and spallation sources as well. With respect to the high costs of a modern neutron source guides play an important economical role. Large experimental areas around a neutron source can be opened with neutron guides and the number of experiments can be multiplied. Instead of one or two instruments at a beamtube a set of a few guides with two or even more instruments per guide can be installed at each beam tube. Up to now the large vertical divergence at the exit of a beam tube favours the installation of spectrometers directly at the reactor pool. With the development of sophisticated super mirrors with large reflection angles a high vertical divergency can also be obtained at the exit of a guide and in principle at a future „neutron factory" no instrument must be installed near the core, but all instruments may be set up in a series of external guide halls with easy access and with an only small, but highly protected central „reactor-building". Moreover there are many qualitative improvements and optimizations of experimental conditions offered by guide tubes: By curvature of the guide (radius of curvature 0.1 km < R < 10 km) one gets a pure neutron beam with low background and a defined wavelength cut-off, and by appropriate use of neutron mirrors beam splitters, focussing devices, deviators and polarizers can be built. At high performance spallation sources guides become even more important, because energy analysis is mostly done by the time-of-flight method and for high resolution spectrometers long flight paths are needed, which can only be realized effectively with guide tubes.

The new neutron source FRM-II is designed with one especially large beam hole (diameter at the outer pool wall ~1.2 m), which looks onto a cold source of D_2. Six neutron guides start inside this beam tube and enter, through an 18 m long guide tunnel) a guide hall ~ 50 m long and ~25 m wide, inside which more than a dozen instruments can be installed. Most of all other horizontal beam tubes can be equipped with one or two guide tubes, either thermal guides (beam tubes SR-5 and SR-8) or cold guides (beam tube SR-4). Moreover a very cold beam can be extracted through a vertical guide directly from inside the cold source.

2. Design of the guides

Many of the existing neutron guides were installed into existing beam tubes at existing reactors. With the new FRM-II we could design most of the beam tubes and guides according to the special demands of the experimentalists and thus the performance of many instruments can be improved. Especially the development of and experiences with super mirrors, the most important contribution to neutron guides during the last two decades, were taken into account for our design.

The basic design principles for our guides were: (1) Keep the length of direct sight of the curved guides as short as possible in order to maximize the distance from sources of background radiation to the instruments within the limits of a given building. A curved guide scatters background radiation out of the beam within the length of direct sight, which is given by $L_I = 4A/\gamma^*$, where A is the channel width of the guide and γ^* the maximum reflection angle for the characteristic wavelength λ^* of the guide. By subdividing the total channel width A of a guide by (n – 1) thin glass plates into n subchannels the length of direct sight can be reduced by a factor n. Coating the reflecting vertical sidewalls with super mirror with the characteristic multiplication factor m reduces the length of direct sight by an additional factor m, which is m = 2 for most guides of FRM-II. All the background from the guides can thus be kept nearer to the reactor and the shielding along the guides can be kept shorter and more compact.

(2) For long guides and long wavelength neutrons find an optimum combination of coating the guide with nickel or Ni-58 and coating with super mirror. The totally reflecting nickel and Ni-58 have a reflectivity as high as 99.5 %, but a smaller glancing angle than a super mirror. On the other hand, a super mirror has a larger maximum reflection angle, but a smaller reflectivity, which normally decreases from 99.5 % at m = 1 (maximum glancing angle of natural nickel) to about 88 – 90 % at m = 2. The reduced reflectivity in the super mirror regime is caused by imperfections in the multi-layer system, which works on the optical principle of interference and not on the principle of total reflection. Long wavelength neutrons in a long guide may undergo more than 10 reflections and the losses due to the reduced reflectivity of the super mirror may be severe. One can obtain a higher transmission by a guide, which starts with Ni-58 and a width, which is larger than needed, and ends in a short section of, say, 8 - 10 m with converging walls, coated with super mirror. Alternatively one can start also with a divergent section coated with super mirror, followed by a parallel section coated with Ni-58 and ending in a convergent section coated with super mirror. The results of Monte Carlo simulations of such guides were reported in [1]. The gain by a proper choice of geometry and coatings may be as large as a factor 2 - 3. Nevertheless, one should note that the use of super mirrors can increase the neutron current at the end of a guide, but not the brilliance.

(3) Find an optimum geometry for the guide which fits to a special instrument at the end of a guide. As a first example we consider the guide, which will supply a high resolution Time-of-Flight spectrometer at the FRM-II [2] with neutrons. Such an instrument needs a number of very fast spinning disk choppers with neutron absorber at the circumference. Because of centrifugal forces the mass of the absorber should be as low as possible. This condition can be best fulfilled, when the neutron beam is free from high energy neutrons because of the energy dependence of cross sections of standard absorber materials. It was already shown in very early neutron guide papers [3],[4], that a curved single-bend guide transmits some high energy neutrons (via so-called garland reflections), whereas a double-bend, S-shaped guide has a well-defined high energy cut-off in the transmission function. As anyhqw the high energy neutrons are not needed for spectroscopy by such a beam-filtering in an S-shaped guide one needs less absorbing material on the chopper disk. Thus highest chopper speeds and best spectrometer resolution can be obtained.

As a second example how to create an adequate beam cross-section and an adequate divergence by proper guide geometry we want to describe a guide especially designed for a neutron reflectometer for the study of liquid and biological materials [5]. For samples with a horizontal surface one wants in a reflectometer a very flat beam with a small divergence in the vertical direction and a broad beam with a large divergence in the horizontal direction. In a standard neutron guide configuration one normally has beams with a narrow horizontal width and a large vertical direction. For a cross-section transformation one could think of a two-dimensionally conical guide, which is divergent in the horizontal and convergent in the vertical direction. This would result however, according to Liouville´s theorem, in a beam with a large vertical and a small horizontal divergence, which is just the opposite of what is needed. We therefore have designed a „twisted“ neutron guide, which is shown in figure 1. Starting from a guide 12 mm wide and 170 mm high with nickel or Ni-58 on the vertical side walls and with super mirror on the narrow top and bottom plates the rectangular cross-section is twisted by 90° on a length of 36 m around the horizontal axis. At the end of such a guide the horizontal divergence should be that of the super mirror and the vertical divergence that of the nickel coating. Finally the horizontal width can be compressed and the horizontal divergence enlarged by a horizontally conical guide with the vertical side walls coated with super mirror of m up to 4 or even higher if possible. At the end one should get a beam about 50 – 60 mm broad, about 12 mm high with a narrow divergence in the vertical and a wide divergence in the horizontal direction such as it is ideal for a reflectometer with a horizontal sample surface. The transmission behaviour of that guide was studied by Monte Carlo calculations, which confirmed our qualitative expectations.

(4) Create as many „guide end positions“ as possible. The cross-section of a primary neutron guide is normally much larger than what is needed for an experiment and a guide beam can be shared by several instruments. The most versatile situation is one in which partial beams can be separated from each other by so-called beam benders with different radii of curvature. The splitting of the cross-section of the primary beam can be either in the vertical or in the horizontal direction. End position instruments do not suffer from other instruments upstream and do not disturb other instruments downstream.

3. Set-up of the Guides

FRM-II will have a large system of cold neutron guides fed by a D_2 cold source behind beam tube SR-1 and a series of thermal guides at beam tubes SR-5 and SR-8. The thermal guides provide instruments in the experimental hall of the reactor building, but most guides, starting from the standard horizontal beam tubes, could be extended into external laboratories via special holes in the walls of the reactor building. At beam tube SR-5 a polarizing guide is being built, which is 10 m long and produces a polarized neutron beam for a triple-axis spin-echo spectrometer. The guide tube has a cross-section 98 mm high by 44 mm wide, where the width of 44 mm is subdivided by 4 glass plates 1 mm thick into five channels 8 mm wide. All vertical surfaces are coated by a polarizing super mirror ($m = 2.5$) of remanent FeCo- and TiN- layers. Due to the narrow subchannels the length of direct sight is less than 10 m so that each neutron hits at least once a polarizing mirror surface. Attached to the polarizing channels of each element is another channel 98 mm high and 44 mm wide with non-polarizing mirror walls. As a special feature the complete guide system of 10 m length can be precisely shifted sideways, so that the spectrometer can be supplied either with polarized or non-polarized neutrons.

Two other thermal guides will be installed at the two exits of beam tube SR-8. A high resolution neutron powder diffractometer will be supplied by a 14.5 m long guide with a constant width of 25 mm (sidewalls super mirror $m = 2$) and a height diverging from 100 mm at the beam tube exit to 200 mm (super mirror $m = 3$ at top and bottom plates) at the outer end to fit for a vertically focussing monochromator. The second guide to a single crystal diffractometer is 11.5 m long and has a cross-section of 75 mm high x 50 mm wide at the beginning and 60 mm high x 20 mm wide at the end. The vertical side walls are coated with super mirror $m = 2$ and the horizontal top and bottom plates are coated with super mirror $m = 3$.

The cold guide system at beam tube SR-1 consists of six primary guides with directions to the main axis and cross-sections of +-1° (170 x 50 mm²), +-6.6° (170 x 60 mm²) and +-8.75° (120 x 60 mm²). The six guides in a common housing inside the beam tube have a length of 2.2 m each and are made from boron-free glass. They are coated with Ni-Ti super mirror ($m = 2$) and start at a distance of 2 m from the cold source. A conical mirror box (700 mm long), common to all six guides and made from polished metal plates (nickel coated aluminum with super mirror $m = 2$) is fixed to the source-side end of the guide housing and improves the illumination of the guides for neutrons with wavelength above 10 Angstroem. In total the beam tube is 4 m long and is filled with helium of 1.2 bar (abs). Outside the reactor pool a shutter, which is common to all six beams and rotates around a horizontal axis, is installed. The guide tunnel in the reactor hall has a length of 18 m and continues, beyond the 1.8 m thick wall of the reactor building, into a 10 m long casemate in the guide hall. The guide elements in the tunnel and through the wall of the reactor building will be mounted in vacuum housings. The guides can be closed by very fast safety shutters, which are air-tight integrated into the wall of the reactor building. Depending on size and complexity the guides in the neutron guide hall will be mounted without extra vacuum housings and will be evacuated directly.

The geometry of the individual guides at beam tube SR-1 has been chosen in a way that, at least up to the entry into the neutron guide hall, the complete spectrum of the cold source is transmitted. Moreover the length of direct sight ends, for most of the guides, inside the casemate in the guide hall, resulting from super mirror coating and/or subdivision of the guides according to section 2. Guide NL-1 has a cross-section of 120 x 60 mm² and a total length of 32 m beyond the primary shutter. On a length of 20 m it is subdivided into two channels (equally wide) and delivers neutrons to a reflectometer and a X – TOF spectrometer. Guide NL-2 (170 x 60 mm) is split up into two partial beams (170 x 44 mm²,

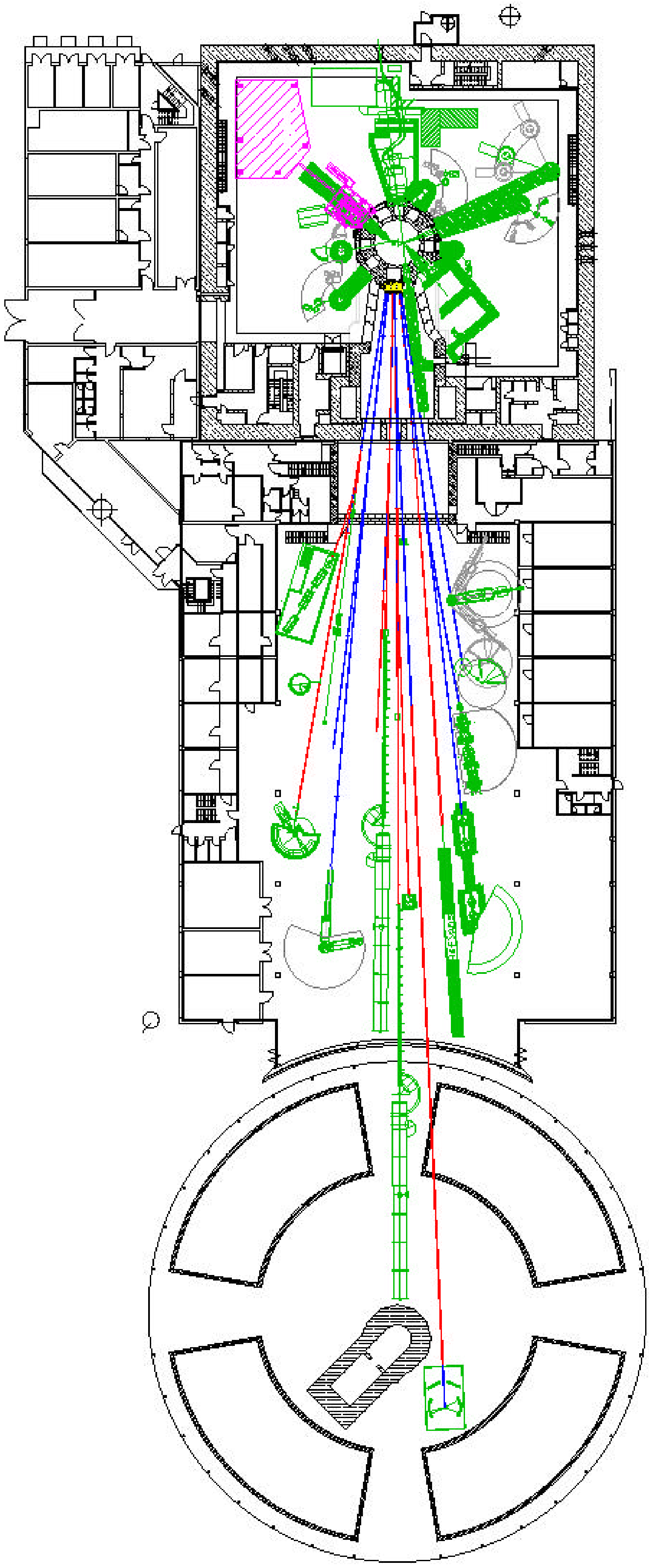

Fig.1 Layout of the experimental installations at FRM-II

radius of curvature 2000 m and 170 x 12 mm², radius of curvature 400 m). The narrow guide changes beyond the safety shutter into the „twisted“ guide (36 m long) for a biological reflectometer. One part (100 x 44 mm²) of the other beam will be used by a TOF spectrometer and the remaining part (50 x 44 mm²) by a spin-echo spectrometer. Guide NL-3 (170 x 50 mm²) is subdivided into a lower part (45 x 50 mm², radius of curvature 1500 m) and an upper part (116 x50 mm², radius of curvature 460 m). These beams will be used for prompt capture gamma analysis (PGA), a small-angle instrument and for a high resolution TOF diffractometer as soon as financing is clear. Guide NL-4 (170 x 30 mm², radius of curvature 1000 m) will be built up to the safety shutter and will be used according to future requirements. Guide NL-5 (cross-section 170 x 60 mm², radius of curvature 1640 m) is subdivided into two channels on a length of 12 m. Beyond the safety shutter a part of cross-section 170 x 30 mm² will be polarized in a 30 m long polarizing curved guide (FeCo, TiN) with a permanent magnetic guide field . Guide NL-6 has a cross section of 120 x 60 mm². Beyond the safty shutter a partial beam (120 x 10 mm²) of very cold neutrons is reflected by an inclined super mirror into a side-channel for neutron optical experiments. The rest of the beam will be used by a back-scattering spectrometer and a diffuse neutron spectrometer. The complete arrangements of guides and instruments including those in the old reactor hall is shown in figure 1. The scheme of cross-sections of the cold guides is shown in figure 2.

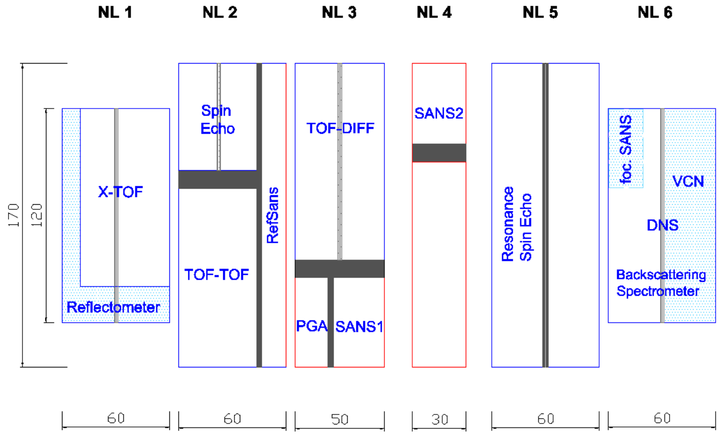

Fig. 2 Scheme of cross-sections of the cold guides at beam tube SR-1

4. Summary

The new research neutron source FRM-II (Forschungsreaktor München – II) will be the most modern and most powerful neutron source in Germany, when it becomes operational in 2001/2002. With the design of beam tubes and neutron guides a high flexibility to fulfill future demands by experiments was aimed at. We hope that by accomodation of the characterisric data of the neutron guides to special features of the spectrometers optimum conditions for experiments will be available.

5. References

[1] Aschauer, H.; Fleischmann, A.; Schanzer, C.; Steichele, E.: „Neutron Guides at the FRM-II“; Physica B 283 (2000) 323 – 329
[2] Roth, S.; Zirkel, A.; Neuhaus, J.; Petry, W.; Schneider, W.: „Optimization of a Neutron Guide System for the Time-of-Flight Spectrometer at the FRM-II“; Physica B 283 (2000) 439 – 442
[3] Alefeld, B.; Christ, J.; Kukla, D.; Scherm, R.; Schmatz, W.: „Neutronenleiter“;Kernforschungsanlage Jülich Jül – 294 NP; 1965
[4] Buzano, C.; Demichelis, F.; Rasetti, M.: „Doubly bent total reflecting Tube as Cold Neutron Filter“; NIM 47 (1967) 320 – 326
[5] Kampmann, R.: „REFSANS“; GKSS Forschungszentrum Geesthacht; Internal Report; 2000