HIGH CURRENT ACCELERATOR-DRIVEN NEUTRON SOURCE PLATFORM OVERVIEW

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Abstract

ESS-Bilbao, JCNS, and LLB have joined forces to develop Europe's first HICANS Platform (HiCANS stands for "High Current Accelerator-driven Neutron Source"). This project aims to integrate the high current proton accelerator system, currently under construction at ESS Bilbao, with the target-moderator-reflector unit that has been successfully built and operated at Forschungszentrum Jülich, and a diffractometer and a reflectometer to be installed and operated by LLB, plus additional neutron instrumentation provided by the three partners. This facility intends to validate and demonstrate the technological developments that will take part of these medium-flux neutron sources.

In this demonstrator, the first stage of the ARGITU source will be used to produce a pulsed proton beam with an energy of 3 MeV and a repetition rate of 30 Hz hitting a lithium target, generating neutrons that are then moderated at the desired thermal and cold energy ranges for the operation of a diffractometer and a reflectometer.

INTRODUCTION

High-current accelerator-driven neutron sources (HiCANS) are being developed to complement the decreasing availability of reactor-based neutron beam time in Europe. The HiCANS platform at ESS-Bilbao (Fig. 1) is conceived as an integrated demonstrator for a compact pulsed proton driver, a dedicated target–moderator station, and neutron scattering instrumentation. It brings together the ARGITU accelerator development in Spain, the Jülich target station experience, and LLB instruments formerly operated at reactor and CANS facilities. The main objective is to demonstrate reliable production, moderation and transport of useful thermal and cold neutron beams at moderate accelerator power, while preparing the route towards future higher-power HiCANS facilities.

ACCELERATOR

The accelerator will deliver a pulsed high-current proton beam of 3 MeV, with pulses up to 1.5 ms at 30 Hz and a peak current of up to 30 mA. The front end consists of a proton ion source, a Low Energy Beam Transport (LEBT) section and a Radio-Frequency Quadrupole (RFQ). The ion source provides an approximately 45 keV beam, which is matched by the LEBT into the RFQ [1]. Solenoidal focusing in the LEBT controls the transverse envelope and mitigates space-charge effects, with the objective of preserving emittance and maximizing RFQ capture. The RFQ (Fig. 2) is the main accelerating structure of the linac. Operating at 352.21 MHz, it bunches, focuses and accelerates the incoming proton beam to about 3 MeV. Simulations using the manufactured field-map geometry predict high transmission over the expected current range, providing beam parameters compatible with transport to the neutron-production line.

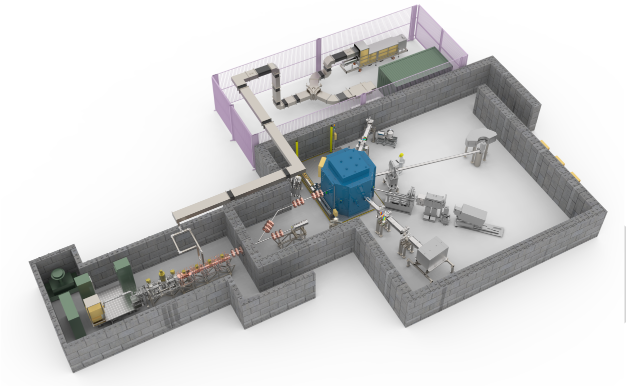

Figure 1: HiCANS platform to be installed at ESS-Bilbao, Zamudio, Spain: accelerator, transfer line, target station and neutron instruments.

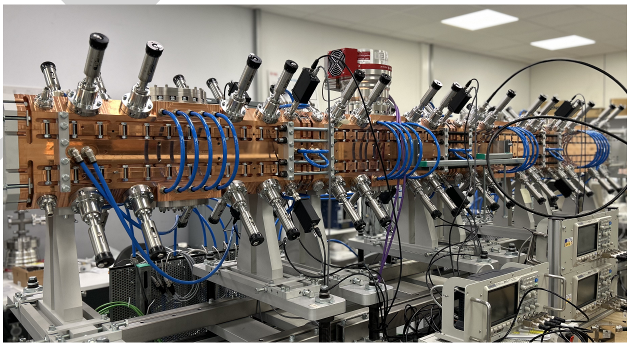

Figure 2: RFQ during the bead-pull campaign in the integration laboratory.

Downstream of the RFQ, a dogleg-type transfer line [2] transports the 3 MeV beam towards the lithium target while providing diagnostics, steering and beam-size control. The main branch uses a dipole deflection to direct the beam to the target and reduce direct exposure to ionizing radiation produced at the target. A secondary, undeflected branch terminates in a beam stop for commissioning, tuning and safe disposal during start-up or transient operating conditions. Beam position, profile, current and emittance diagnostics

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are included to support accelerator tuning and machine protection.

NEUTRON TARGET STATION

The neutron target station contains the lithium target, moderators, extraction channels and biological shielding. It is assembled from 27 shielding blocks surrounding a 1 m^3 inner core that houses the target–moderator–reflector (TMR) assembly (Fig. 3) [3]. One shielding segment can be opened to provide access to the TMR. Safe operation is provided by approximately 1 m of alternating borated polyethylene and lead in each shielding block; the complete station is about 3 m long and 3.1 m high.

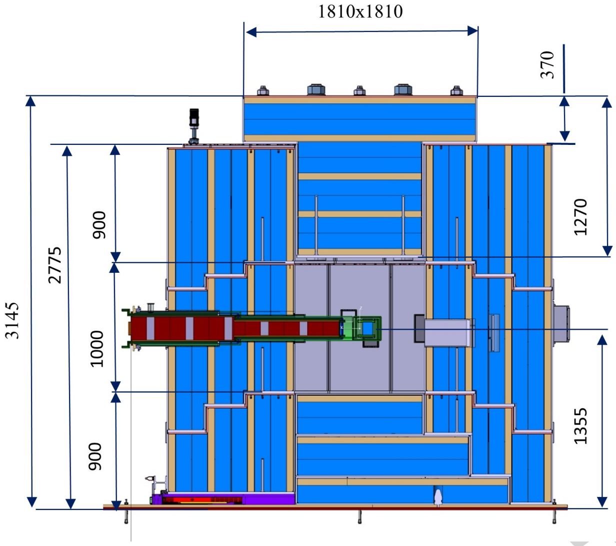

Figure 3: Vertical cut through the target-station shielding with the target plug.

Neutrons are produced through the $^7\mathrm{Li}(p,n)$ reaction. The target consists of a 0.2 mm thick lithium disc, 8 cm in diameter, bonded to a copper backing plate and protected by a thin titanium layer against oxidation. The lithium layer is thinner than the penetration depth of 3 MeV protons, reducing radiation damage in the lithium. Beam heat is removed by water cooling integrated in the copper backing plate, designed for a 5.8 kW thermal load for a Gaussian beam distribution.

The target is mounted on a plug inserted into an L-shaped vacuum tube in the TMR. The plug positions the target, completes the local shielding and supplies cooling water. Since the target becomes activated during operation, remote exchange is performed with a dedicated device already demonstrated at the Jülich Neutron Platform (JNP) [3]; the tool also provides local lead shielding during handling.

Eight neutron extraction channels are embedded in the shielding (Fig. 4). The channels serving the reflectometer and diffractometer are inclined by $\pm 11^\circ$, cross in front of the target and are vertically separated by 7 cm, allowing insertion of thermal or cryogenic moderators through the extraction ducts. The thermal water moderator is positioned about 2 cm behind the target. It has a depth of about 13 cm, transverse dimensions of about 30 cm × 30 cm, and is surrounded by a lead reflector. Extraction plugs carry neutron guides within roughly 40 cm distance to the maximum thermal flux. The channels nearly parallel to the target surface can host a one-dimensional para-hydrogen cold moderator with cryogenic feeding lines routed through the extraction plug.

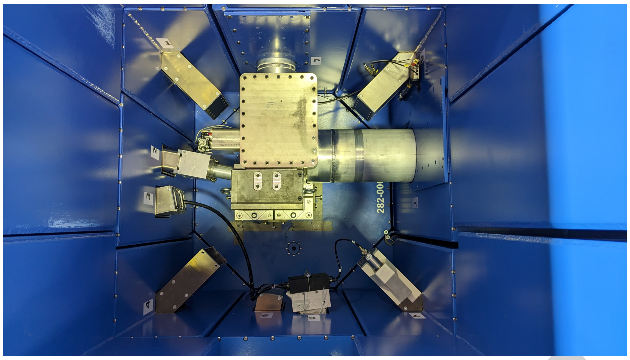

Figure 4: Top view into the target station shielding with the target-moderator-reflector unit and the eight extraction channels.

NEUTRON INSTRUMENTS

HERMES Reflectometer

HERMES is a compact time-of-flight reflectometer from LLB, formerly operated at the Orphée reactor and recently tested at the Jülich Neutron Platform [4]. Neutron reflectometry probes thin films and interfaces, typically from a few to about 100 nm, and is particularly useful for polymer and biological films, solid–liquid or air–liquid interfaces, and magnetic multilayers. The technique benefits from isotopic contrast, especially between hydrogenated and deuterated materials, and from the sensitivity of neutrons to magnetic depth profiles.

Reflectometry is well matched to a pulsed source because a broad wavelength band can be recorded at fixed sample angle using time-of-flight analysis. This allows a significant part of the reflectivity curve to be measured without moving the sample, while making efficient use of the neutrons in each pulse. HERMES is therefore a suitable first instrument for the HiCANS Platform: it was designed for high flux and moderate resolution, and its compact geometry of about 5 m from collimator entrance to detector remains close to the former Orphée configuration, where the flight path was only 6.25 m (Fig. 5). This short layout simplifies integration in the ESS-Bilbao experimental area while preserving the essential instrument concept.

Cold neutrons are preferred for reflectometry because the neutron optical index leads to small critical angles, typically of the order of one degree. Although HERMES was originally designed for samples such as two-inch wafers, the sample environment can accommodate larger surfaces. During the accelerator ramp-up, samples of order 100 cm^2, for example neutron super-mirror samples, can be used to compensate for the lower initial source flux and to match the measurement programme to the available performance.

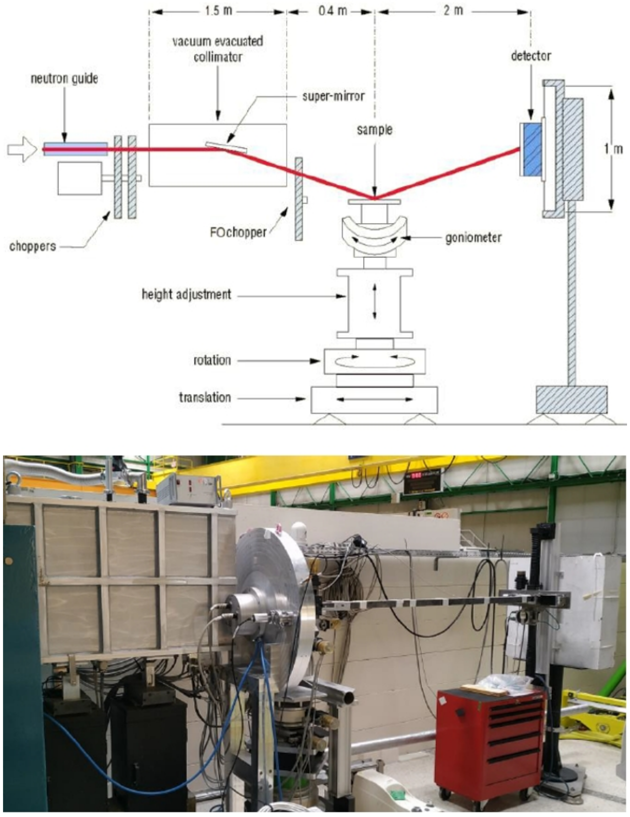

Figure 5: (a) HERMES reflectometer design; (b) instrument layout at Orphée.

The recent HERMES campaign at the Jülich Neutron Platform (JNP) provided an important benchmark for HiCANS platform [4]. The instrument was operated with a 40 MeV proton beam at very low current[1] and only about 1 W target power, yet reflectivity over 2–3 orders of magnitude was measured, indicating that the instrument background can be controlled well on a compact accelerator-driven source. Proton beam operation at 3 MeV and about 4 kW average beam power is expected to provide a fast-neutron yield of about $25 \times 10^{11}\,\mathrm{n_{fast}/s}$, compared with about $3 \times 10^{11}\,\mathrm{n_{fast}/s}$ at JNP for 1 W. Since HERMES has already been tested successfully there, recommissioning after installation at the HiCANS Platform is expected to be comparatively rapid.

Powder Diffractometer

A powder diffractometer will be installed as a test instrument for neutron scattering on the pulsed HiCANS Platform. Although accelerator operation will provide a long-pulse of about 1.5 ms, and the limited initial flight path will not provide state-of-the-art diffraction resolution, the instrument will enable useful studies such as phase-transition measurements and will provide experience with powder diffraction on the pulsed source. The proposed prototype reuses elements of the former LLB 3T2 diffractometer. Its detector consists of 50 ^{3}He tubes, 20 mm in diameter and 250 cm high, covering a solid angle of about 0.3 sr.

CONCLUSION

Coordinated efforts to develop such kind of neutron sources and eventually demonstrate the realization of a facility of this type are under way in several countries, like HBS [5] in Germany, ICONE [1] in France, or ARGITU [6] in Spain. The HiCANS Platform will demonstrate the integration of a reliable 3 MeV high-current accelerator, lithium target, moderator and extraction system with compact neutron instruments. By combining ESS-Bilbao accelerator infrastructure, the Jülich target-station concept and LLB reflectometry and diffraction instrumentation, the project will validate the technologies and operational procedures needed for future compact accelerator-driven neutron sources in Europe.

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[1] of the order of 1 μA.