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Conceptual design of the beryllium rotating target for the ESS-Bilbao facility

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ABSTRACT

The ESS-Bilbao facility, hosted by the University of the Basque Country (UPV/EHU), envisages the operation of a high-current proton accelerator delivering beams with energies up to 50 MeV. The time-averaged proton current will be 2.25 mA, delivered by 1.5 ms proton pulses with a repetition rate of 20 Hz. This beam will feed a neutron source based upon the Be (p,n) reaction, which will enable the provision of relevant neutron experimentation capabilities. The neutron source baseline concept consists in a rotating beryllium target cooled by water. The target structure will comprise a rotatable disk made of 6061-T6 aluminium alloy holding 20 beryllium plates. Heat dissipation from the target relies upon a distribution of coolant-flow channels. The practical implementation of such a concept is here described with emphasis put on the beryllium plates thermo-mechanical optimization, the chosen coolant distribution system as well as the mechanical behavior of the assembly.

1. Introduction

The advent of important developments in accelerator technology as well as the dissemination of neutronic design capabilities has enabled the construction of small to medium scale accelerator-driven neutron facilities which, are nowadays playing a significant role in the development and optimization of large facilities. In fact, a number of small-to-medium range installations worldwide are now in operation, under construction or planned. The role of these facilities is glaringly shown by work performed on moderator and instrument development carried out at laboratories such as the Low Energy Neutron Source (LENS) facility at the University of Indiana (EE.UU) in relation to the SNS project (Oak Ridge National Laboratory, EE.UU) [1,2], or the activities developed within the Hokkaido University electron linac regarding the MLF J-PARC facility (Tokai, Japan) [3]. In addition, a number of neutron facilities are now under construction mostly relying on proton accelerators as drivers. Most of them cover a wide spectrum of activities which, apart from neutron scattering purposes, also envisage activities in other areas such as Accelerator Driven Systems (ADS) for waste transmutation, hadron therapy, neutron imaging, etc.

The developments just referred to open up new opportunities for university scale organizations to enter the field of neutron physics with modest investments, carrying out activities within fields as diverse as materials science, nuclear physics, medical physics, engineering and cultural heritage [4]. As a matter of fact, small to medium power sources may provide invaluable experimental resources, useful for the development of neutron techniques and training of the neutron users and accelerator and source operators. Not all measurements or experiments require the beam intensity offered by the high power sources, and excellent science programs can be carried out at smaller facilities. Small sources can be adapted to a specialized community, which may better reflect the regional requirements. Scientific and technological experiences and know-how developed at such sources are shared effectively with the larger facilities. Hence, covering all the needs of the user community, low, medium and high power neutron sources should be considered as complementary, each playing an important role in the application and advancement of neutron techniques, as recently emphasized by a report of a working group of the Institut Laue Langevin (ILL) associates [5].

Within the above sketched framework, the ESS-Bilbao project seeks to channel the Spanish contribution to the European Spallation Source (ESS) project [6], as well as to develop in-house capabilities in accelerator science and technology. For such an avail, a compact although high power proton and $^{-}$H accelerator is

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Table 1
ESS-Bilbao accelerator main parameters.

Proton energy	50 MeV
Peak current	75 mA
Repetition rate	20 Hz
Pulse length—variable	1.5 ms
Average current	2.25 mA
Average power	112 kW

Table 2
Neutron Yield for different target materials for 50 MeV protons, calculated using ENDEF-VII/B[10] cross-sections.

Material	N/p	Av. energy (MeV)
Carbon	7.5×10^{-3}	8.0
Lithium	4.3×10^{-2}	13.3
Beryllium	6.5×10^{-2}	7.8

now under construction. The machine has been designed to feed several irradiation laboratories as well as a neutron generation target, the design of which constitutes the issue of the present work.

2. Conceptual target design

The accelerator under construction in Bilbao will drive a compact neutron source whose design will be based on a rotating beryllium target cooled by water. The neutron yield expected for such a medium-sized source comes to about ~10^{15} n/s [7]. Such a neutron fluence is however large enough to carry out relevant experimental tasks such as testing components and subsystems (moderators, neutron guides, neutron detectors, choppers or even instrument concepts) to be installed at the ESS facility, develop projects in collaboration with other large-scale facilities, as well as to train local neutron scattering users. The main parameters of the ESS-Bilbao accelerator are summarized in Table 1.

A glance to data about the accelerator design parameters of several neutron sources compiled in Ref. [7], shows that the beam delivered by the ESS-Bilbao machine largely differs from those employed in neutron production facilities based upon spallation reactions, and on the other hand, delivers significantly more power than that handled at other university-scale neutron facilities such as LENS. Nevertheless, it falls within the range of those used to build low energy converters for the generation of radioactive ion beams like SPIRAL2 [8] at GANIL (Caen, France) or INFN [9] (Legnaro, Italy). For these low energy targets, lithium, beryllium or carbon (graphite) are the materials of choice. The latter is preferred due to its reasonable production efficiency for stripping (d,n) reactions, its very good thermo-mechanical properties and the possible use of heat radiation cooling for moderate ion currents. However for 50 MeV protons the neutron yield of a carbon target is about one order of magnitude lower than that provided by other light elements such as lithium or beryllium (Table 2). Besides, since the main purpose of the ESS-Bilbao target is to deliver thermal and cold neutron beams, thermal or cryogenic moderators must be placed as close as possible to the target [7], precluding the use of radiation cooling and making less interesting the use of carbon. This, together with the better mechanical properties of beryllium and its easier handling compared with metallic lithium and other lithium-based alloys, makes beryllium the material of choice.

As regards the cooling of the ESS-Bilbao target, a low-pressure flow of water appears as the most adequate option. Such a coolant ensures the necessary heat-removal capacity given the thermal power densities involved [11], and presents several other advantages like the existing operational experience within nuclear industry, the availability of off-the-shelf nuclear and vacuum-grade circuit components (pumps, feedthroughs, seals, etc.), and the possibility of hands-on maintenance of parts of the cooling loop. As an added bonus, the design here considered may profit from the experience of other beryllium–water based facilities, such as in operation at LENS [12] or the system built at the National Institute of Radiological Sciences (NIRS) Center (Chiba, Japan) [13]. However both are stationary targets which operate at a far lower power (8 kW for LENS and 3.2 kW for NIRS) than that delivered by the ESS-Bilbao accelerator. Assuming that the maximum heat flux which can be removed by single-phase (non-boiling), low pressure water is about 1 MW/m^2 ($h\approx10^4$ W/m^2 K, $T_{surf}-T_{bulk}\approx100$ K) and given the ESS-Bilbao beam power density (1.12×10^5 W and $<10^{-2}$ m^2 cross-section), the implementation of a rotating target design becomes mandatory; even if the sharply pulsed nature of the heat load is neither explicitly taken into account nor the associated thermo-mechanical effects considered.

3. ESS-Bilbao target description

On the grounds of considerations given above, the design of the ESS-Bilbao target will consist of a rotating disk holding water-cooled beryllium plates as it is sketched in Fig. 1. The conceptual design of such a target benefits from the analysis done during the design phase of other rotating target projects such as the second target station project SNS [14] or that regarding the German SNQ project [15], and from the experience acquired during the manufacturing of the rotating target flow test stand [16]. This test stand, built and operated within the ESS-Bilbao facilities, simulates the solid rotating design option for the second target station of SNS, within the framework of a collaborative agreement established between the two institutions.

The structural material of the disk will be the 6061-T6 aluminium alloy. The inner cooling circuit will be basically defined by the space between the disk components. The coolant enters into the disk through its axis, is then distributed radially to the beryllium plates through the upper distribution channels, gets back towards the disk center through the collection of lower channels, and leave it coaxially through the disk axis as shown in Fig. 2. The whole disk assembly is about 2 m in diameter and 15 cm thick.

To ensure that every beam pulse hits a different beryllium plate, the accelerator and target will be synchronized using for the purpose information provided by the installation master clock and

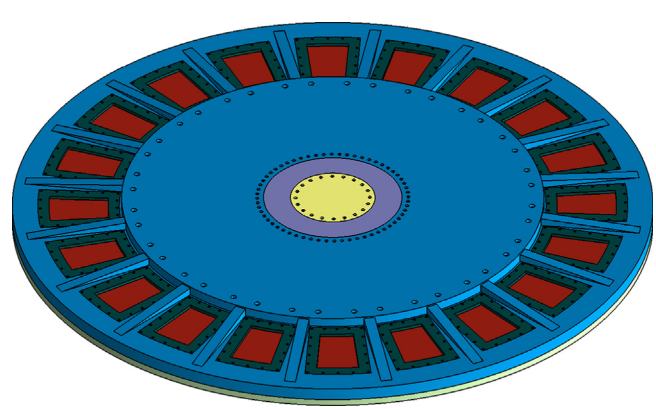

Fig. 1. ESS-Bilbao target overview.