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The neutron target station of the Compact Pulsed Hadron Source

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ABSTRACT

A long-pulse compact neutron source will be built at Tsinghua University as a part of the Compact Pulsed Hadron Source (CPHS) Project. CPHS generates neutrons by means of a proton linac (13 MeV, 16kW, 50Hz, ~0.5ms pulse width) and a target station (Be target, moderaors & reflector) to support at least 2 beamlines initially, a small-angle instrument and an imaging/radiography station. Our objective is to realize, in approximately 3 years, a compact, medium-flux neutron experimental platform with viable flexibility for basic research, education, and instrumentation development. Furthermore, the CPHS Project is motivated by its role in supplementing research and development of accelerator-driven neutron/proton facilities in China and abroad. In this paper we describe the design goal and the neutronic performance of the CPHS target-moderator-reflector (TMR) configuration.

1. Introduction

In 2009 Tsinghua University approved a new project for the construction of a Compact Pulsed Hadron Source (CPHS) on the university campus in Beijing, China. The CPHS Project, led by the Department of Engineering Physics, consists of a proton linear accelerator, a neutron target station, and beam lines for neutron and proton applications. The accelerator system employs an ion source, a radio-frequency quadrupole and a drift tube linac to accelerate the protons to 13 MeV. The neutron target station is responsible for thermal and cold neutron production based on the Be(p,n) nuclear reaction, supplying cold neutrons to at least 4 beam ports. Two neutron beamlines will be configured to support a small-angle scattering instrument (SANS) and an imaging/radiography station. These three components—proton linac, neutron target station, and 2 neutron instruments—comprise the first phase of the CPHS Project, to be completed in about 3 years. Additional neutron and proton beamlines and instruments will be added in the second phase of the project. The main design parameters of CPHS are listed in Table Ⅰ. More details of the CPHS and the long-term goals of neutron and proton applications are given in another paper by W. Jie at al. in this proceedings.

Table Ⅰ Primary Parameters of CPHS

Proton Beam	Proton energy (MeV)	13
	Beam power (kW)	16
	Frequency (Hz)	50
	Peak Current (mA)	50
	Average current (mA)	1.25
	Pulse width (μs)	500
Target	Target material	Beryllium
Moderator	Moderator material	Solid methane(≤20K)
Reflector	Reflector material	Light water

At the outset international collaboration was recognized as an important element of the CPHS project. CPHS is a medium-flux, long-pulse neutron source similar to the Low-Energy Neutron Source (LENS [1]) of Indiana University, USA. The scale of the CPHS neutron operation, at least in the beginning, will be similar to the neutron source of the Hokkaido University, Japan, albeit being an electron linac-driven source. Therefore, the CPHS project benefited substantially from the first international workshop held at Tsinghua University in June 2009 in which neutron scientists from LENS and Hokkaido University were among the participants [2]. After the workshop, we began to consider the optimization of the TMR system referencing heavily the LENS design. The goal is to achieve an optimal cold-neutron flux to support at least 4 beamlines with low strayed fast-neutrons and gamma-ray background. Monte Carlo simulations of various TMR configurations were conducted and the resulted compared. No engineering details related to the actual structure of the TMR system was considered in the simulations.

2. The TMRS (TMR+Shielding) design

2.1 The target assembly

The CPHS target station consists of the target, cold moderator system, reflector, shielding and utilities. The target station generates primary neutrons by the Be(p,n) reaction. The proton–beryllium interaction range is about 1.28 mm for 13 MeV protons within which nearly all the primary fast neutrons are generated. Any practical window material is expected to have a similar proton range. This implies that the Be target should be in vacuum (no window) on the proton side. We assume a thin Be plate (1-3 mm thickness), to be contacted effectively with coolant of deionized water on the neutron side to remove the heat deposited by the proton-target reaction. A monitoring apparatus will feed data of the target environment to a response system (including a fast valve) so as to safeguard against adverse effects due to target failure. The primary neutrons with an average energy at about 3.3 MeV over the range from 0 to 12 MeV, the yield of which is 0.0062 n/p simulated by MCNPX V.2.5.

2.2 The CPHS cold moderator system

An effective moderator-reflector is designed to produce the maximum amount of cold neutrons. Solid methane (CH_4) was chosen as the moderator material by virtue of previous experiences on neutron moderators at medium-flux pulsed neutron sources such as LENS, IPNS, KENS and Hokkaido@Linac [3,4,5,6].

Gaseous methane from a source container is condensed into liquid and then solidified to fill a rectangular cell, similar to LENS design. The refrigerator, PT415, of the Cryomech. Ltd., is to provide the necessary cooling capacity A high-purity aluminium stick is employed to conduct the heat from the moderator to the refrigerator cold stem at 1 m away. The polyethylene plug functions as a neutron reflector and shielding. The heater is provided for controlling the cooling process, preventing the solid methane from blocking the inlet of the moderator cell and for annealing the solid methane. The vacuum chamber is evacuated by a turbo-molecular pump system. The Schematic diagram of the cryogenic system is shown in Fig. 1.

The solid methane is cooled by the second stage of the refrigerator, the heat load of the moderator cell is about 1 W from simulations. The thermal shields and polyethylene plug are cooled by the first stage of the refrigerator which can afford at least 30 W cooling power.

2.3 The TMRS system

A detailed layout of the CPHS is given in another paper by W. Jie et al. in this proceedings. The configuration of the TMR assembly is in part dictated by the layout of the proton accelerator, beam-transport structure and the direction of the neuron beamlines with respect to the available space in the existing experimental halls. We have chosen what we call the 'the raised slab' geometry, as shown in Fig. 2. We assume a 13-MeV proton beam, spread out uniformly over a circular area of 8 cm in diameter, striking in a direction normal to a thin Be plate. The proton beam is steered onto the target station by two bending magnets to avoid the direct back stream of the fast primary neutrons to the accelerator. The solid methane moderator is a slab parallel to and down-stream of the Be plate but translated vertically above the proton beam. With the neutron beam holes viewing the moderator surface, the neutron beams will avoid the direct proton beam line, thereby staving off the fast neutrons along that direction [7]. The 'raised slab' geometry of target and moderator are contained by the water as reflector.

Surrounding the reflector assembly is the decouple used to absorb the escaped neutrons, which can cut the tail of neutron pulse. Borated polyethylene composite and lead layers function as the shielding, the design criteria of the shielding is that the dose outside the target station shielding less than 10 mSv/h. Again, the LENS design is amply referenced.

3. The simulated neutronic performance

Computer simulations of the TMR performance were carried out using the MCNPX V.2.5 code. The neutron flux serving the SANS beam line, assuming a circular cross section of Φ10 cm, at 1000 cm from the moderator surface was calculated and shown in Fig. 3. The temporal response of the TMR system was simulated by tallying the leakage of neutrons over the instruments side of the cold moderator face emission in a forward cone ($\cos\theta>0.95$), shown in Fig. 4, and then the FWHM of the time distribution is calculated from the results, shown in Fig. 3.

The FWHM is dominated by the proton pulse width at short wavelength (<0.5 Å), then it is increased with the wavelength, as more collisions with the moderator are required to slow the neutrons to long wavelength. As the neutron energy (wavelength) becomes comparable to the thermal energy of moderator temperature (>2 Å) the neutrons become equally likely to gain or to lose energy in a collision (quasi-equilibrium), and the emission time FWHM saturates at ~300 μs.

4. Summary

The TMR geometry of CPHS neutron target station was designed and the simulated performance is evaluated for the design of neutron instruments. Further enhancement on the TMR performance such as the possible use of a cold beryllium filter (reflector) or a grooved moderator is under way by Monte Carlo simulations. More engineering design of the TMRS and the design of the utilities need to be done in the future.

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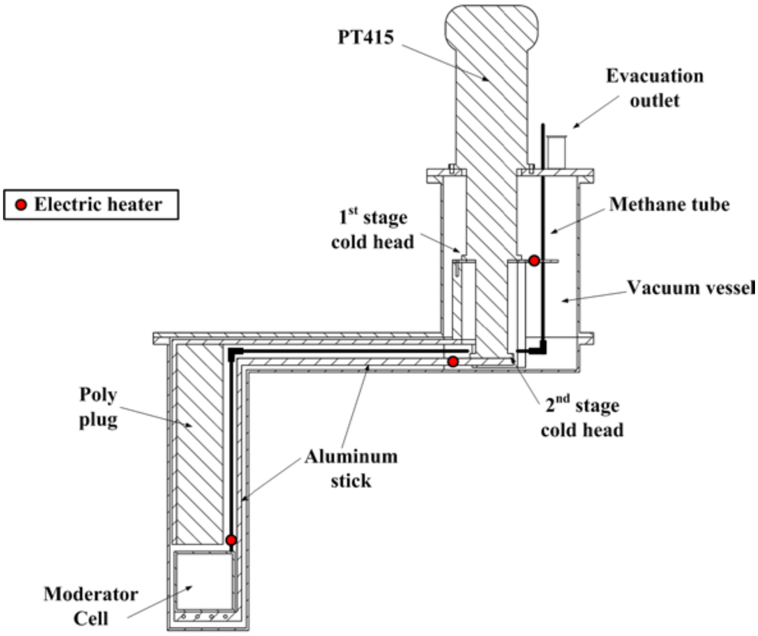

Fig. 1 Schematic diagram of the cryogenic system for cooling down the cold moderator

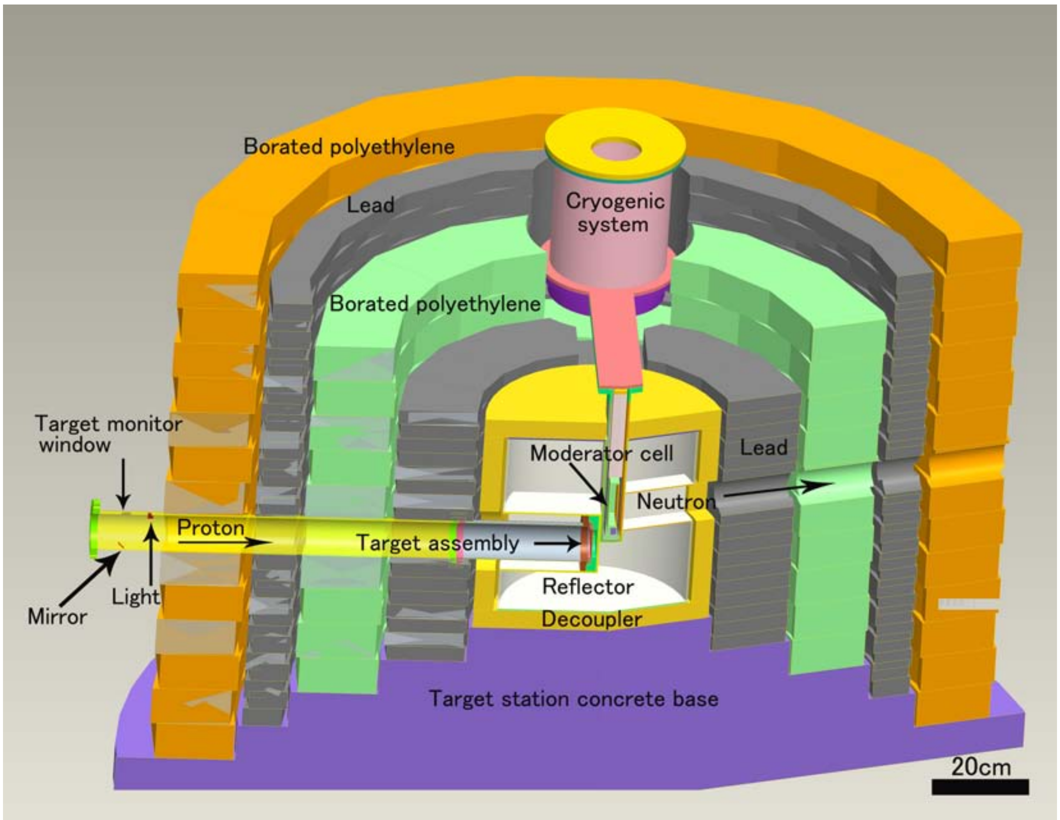

Fig. 2 Anatomy of the CPHS Target – Moderator -Reflector Shielding (TMRS) assembly

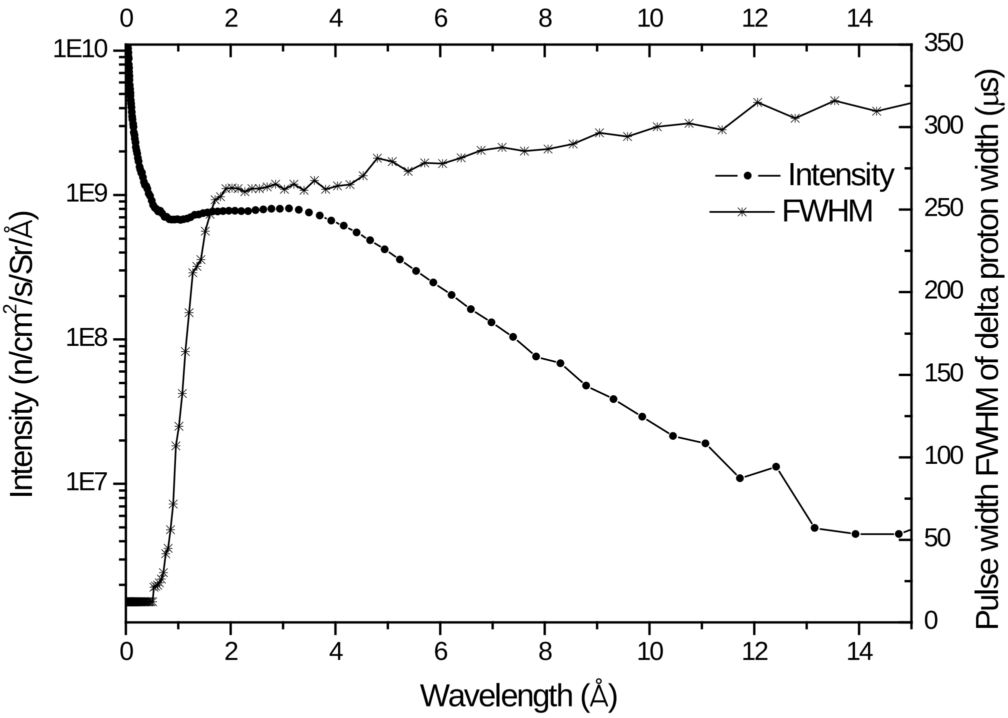

Fig. 3 Simulated neutronic performance of TMR. The intensity distribution is the neutron flux within the SANS beam line at 1000 cm from the moderator surface. The FWHM line was calculated from temporal response of TMR system.

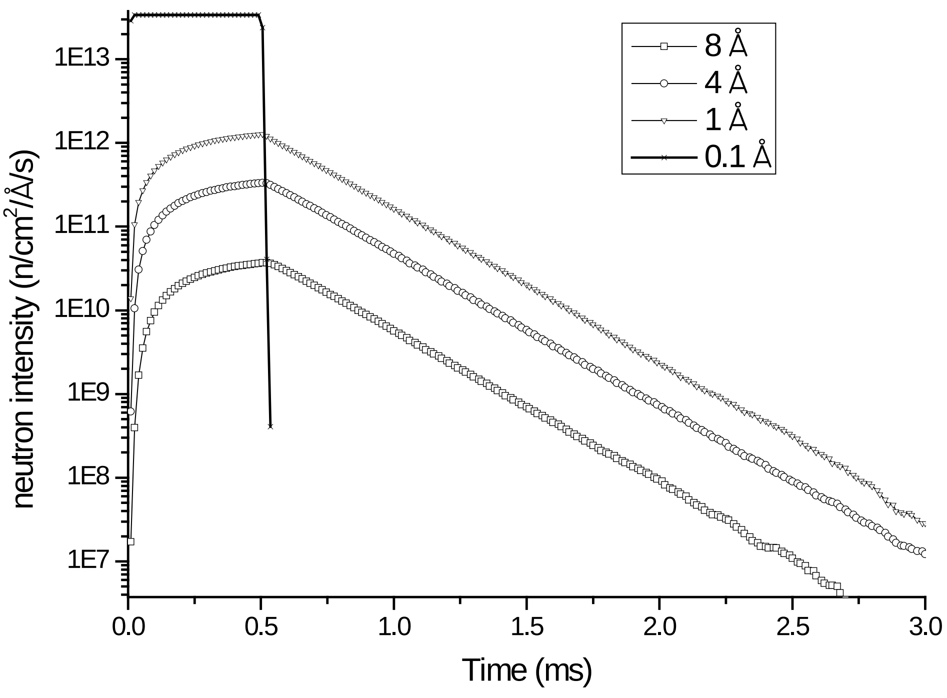

Fig. 4 Temporal response of the CPHS TMR system. Result from the leakage of neutrons over the instruments side of the cold moderator face emission in a forward cone (cosθ>0.95).