

COMPACT PULSED HADRON SOURCE - A UNIVERSITY-BASED ACCELERATOR PLATFORM FOR MULTIDISCIPLINARY NEUTRON AND PROTON APPLICATIONS*

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Abstract

During the past decades, large-scale national neutron sources were developed in Asia, Europe, and North America. Complementing such efforts, compact hadron beam complexes and neutron sources intended to serve primarily universities and industrial institutes were proposed and some have recently been established. Responding to the demand in China for multidisciplinary fundamental and applied research using pulsed neutron and proton beams, from scattering experiments to hadron therapy and radiography to accelerator-driven sub-critical reactor systems (ADS) for nuclear waste transmutation, we here propose a compact yet expandable accelerator complex—a Compact Pulsed Hadron Source (CPHS). It consists of an accelerator front-end—a high-intensity ion source, a 3 MeV radiofrequency quadrupole linac (RFQ), and a 13 MeV drift-tube linac (DTL), a neutron target station—a beryllium target with solid methane and room-temperature water moderators/reflector, and tentatively six neutron stations for imaging/radiography, activation analysis, small-angle scattering, reflectometry, beamline optics development, and therapy. Additionally, the proton beam can be switched to serve multiple proton stations for biotechnological, fuel cell, and nano-applications, as well as space irradiation and detection. In the future CPHS may also serve as an injector to a ring for proton therapy and radiography or as the front end to a superconducting RF linac for accelerator driven sub-critical reactor test programs.

INTRODUCTION

Large, proton-accelerator-driven neutron facilities established in Asia, Europe, and North America are successful in serving users in neutron scattering research with specific instrumentation. However, compact hadron beam complexes and neutron sources at universities permit more flexible education and development of research and industrial applications.

In China, electron-based accelerators are relatively well developed. In comparison to proton-accelerator-based neutron facilities, there are very few: e.g., both the China Spallation Neutron Source (CSNS) [1] and the 2-MeV

deuteron-driven neutron imaging/radiography facility of Peking University [2] are in an early stage of development. Responding to the increasing demand in China for multidisciplinary researches and technological applications using pulsed neutrons and protons, such as hadron therapy and radiography, beam optics, ADS, etc. Tsinghua University has launched a compact yet expandable accelerator complex project which includes the building of a Compact Pulsed Hadron Source (CPHS).

CPHS is driven by a high-intensity proton source, a 3 MeV radiofrequency quadrupole linac (RFQ), and a 13 MeV drift-tube linac (DTL). A Beryllium target with solid methane and room-temperature water moderators serve several neutron instruments. The proton platform serves multiple stations for bio-applications, fuel cell and nano-applications, and space irradiation and detection. CPHS may also serve as an injector to a ring accelerator that subsequently accelerates the beam to up to 300 MeV for proton therapy and radiography [3]. The initial CPHS and subsequent expansion, we anticipate a gradual build-up of a staff of scientists and engineers and accumulation of knowhow and experiences needed to pursue the aforementioned multidisciplinary R&D that require MW-scale hadron facilities.

This paper summarizes major design aspects of the CPHS and discusses its prospective development.

LAYOUT AND PARAMETERS

The CPHS is a newly approved project led by the Department of Engineering Physics of the Tsinghua University, China. This compact facility is to be housed in an existing building on the Tsinghua campus, previously built and used for the now completed cargo-inspecting accelerator systems. As shown in Fig. 2, the CPHS complex consists of a high-intensity proton linac (proton source, RFQ, and DTL) and a beryllium target station for neutron production. Phase 1 of the project also consists of a neutron small-angle-scattering instrument and a neutron imaging/radiography station. Phase 2 of the project consists of instruments for both proton (space irradiation and detection, bio-application, and fuel-cell and nano-applications) and neutron beam lines (for engineering powder diffractometer, reflectometer, irradiation station, neutron therapy, and neutron optical devices R&D). Phase 1 of the project is planned to be constructed in about 3 years. Table 1 shows the CPHS primary parameters. The design goals are an advanced yet reliable, reasonably low

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cost yet expandable platform open to multi-disciplinary users in Tsinghua as well as other scientific and industrial users in China.

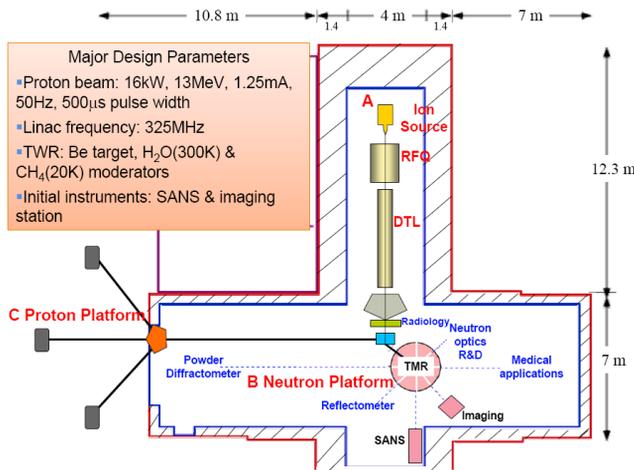


Figure 1: CPHS schematic layout.

Table 1: Margin Specifications.

Proton power on target	16	kW
Proton energy	13	MeV
Average beam current	1.25	mA
Pulse repetition rate	50	Hz
Protons per pulse	1.56×10^{14}	protons
Pulse length	0.5	ms
Peak beam current	50	mA
Target material	Be	
Moderator type	H ₂ O (300K), CH ₄ (20K)	

TECHNICAL SYSTEMS

This section discusses the design rationale of major technical systems. Experiences of previous R&D of CSNS [1] at the Chinese Academy of Sciences and the LENS facility [4] of the Indiana University are heavily referenced.

Ion Source

The proton beam is produced from the electron cyclotron resonance (ECR) ion source at 50 keV of energy (Table 2). The ECR source system consists of the magnetron power source, circulator, dummy load, directional coupler, tuner, and microwave window. The low energy beam transport contains solenoids for focusing and matching and deflecting plates for beam chopping. It also provides space-charge neutralization.

Table 2: CPHS ECR ion source parameters.

Species	proton	
Extraction energy	50	keV
Extraction current	60	mA
Emittance (norm. rms)	0.2	μm

Applications of Accelerators

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Proton ratio	> 90	%
Microwave frequency	2.45	GHz

RFQ

As shown in Table 3, the proton beam is accelerated by the RFQ to 3 MeV. The RF frequency of 325 MHz is chosen so that high-energy extension of the linac can operate at a frequency of 1.3 GHz shared by many R&D programs including the International Linear Collider and Fermilab's Project X. The RFQ system consists of the four-vane cavities, power couplers, RF and its low level control, vacuum, water cooling, beam diagnostics, and survey support. To save space and cost, no medium energy beam transport is planned after the RFQ.

Table 3: CPHS RFQ parameters.

Species	proton	
Extraction energy	3	MeV
Extraction peak current	50	mA
RF frequency	325	MHz
RF peak power	510	kW
Emittance (norm. rms)	0.2	μm
Beam duty factor	2.5	%
RF duty factor	3	%
Vane tip voltage	80	kV
Average aperture	3.565	mm
Section number	4	
Length	3.62	m

DTL

As shown in Table 4, the DTL accelerates the beam to 13 MeV of energy. Electromagnetic quadrupoles are used for tuning flexibility. The DTL system consists of the resonance cavities, drift tubes, focusing quadrupoles, stem couplers, power couplers, RF power sources, magnet power supply, water cooling, vacuum, and control.

Table 4: CPHS DTL parameters.

Species	proton	
Extraction energy	13	MeV
Extraction peak current	50	mA
RF frequency	325	MHz
RF peak power	1.3	MW
Beam pulse length	0.5	ms
Emittance (norm. rms)	0.2	μm
Beam duty factor	2.5	%
RF duty factor	3	%
Magnet duty factor	100	%
Synchronous phase	-30 to -25	degree
Accelerating field	2.2 to 3.1	MV/m
Quad focusing gradient	7.5	kG/cm
Unit number	41	
Length	4.5	m

RF System

Both RFQ and DTL share a single RF power source. The power source consists of high-voltage supply, klystron, pulse modulator, crow bar protection, RF waveguide, low-level control and interlock.

Neutron Target Station and Instruments

The target system consists of the Beryllium target body, two types of moderators, water reflector, neutron transport channel, and shielding. Thermal neutrons produced through the room-temperature water moderator feed the engineering powder diffractometer, neutron irradiation station, and neutron R&D beam-line. Cold neutrons produced through the 20K solid methane feed the small-angle neutron scattering instrument, the reflectometer, the neutron imaging & radiography station, and neutron therapy.

Proton Applications

The proposed proton beamlines are to be used for space irradiation and detection, fuel-cell, bio- and nanotechnology research. Experiences of the PEFP facility [5] of the Korea Atomic Energy Research Institute and the NSRL facility [6] of the Brookhaven National Laboratory are heavily referenced.

FUTURE PERSPECTIVES

Fig. 2 shows possible extensions of the CPHS program. CPHS may serve as an injector to a ring (a slow cycling synchrotron, a rapid cycling synchrotron, or a FFAG) that subsequently accelerates the beam to up to 300 MeV for 3D stereo-tactic proton therapy and radiography.

CPHS may also serve as the front end to an ADS test facility and a large-scale spallation neutron source. For example, this front end can be continued by a 2 GeV superconducting RF linac operating at 1.3 GHz frequency. The same linac may drive an accumulator to produce short-pulsed beams for spallation neutron production at a beam power above 5 MW. To fully serve the ADS purpose, the duty factor of the CPHS front end needs to be significantly increased.

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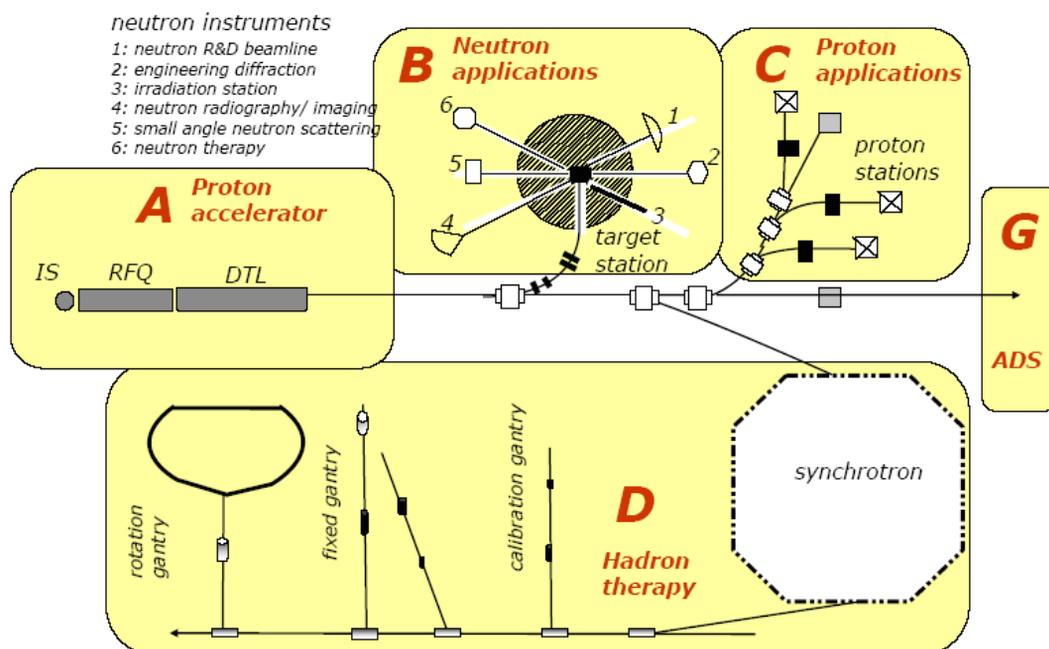


Figure 2: CPHS and possible future extensions.