PRESENT STATUS OF THE HIGH CURRENT PROTON LINAC AT TSINGHUA UNIVERSITY AND ITS BEAM MEASUREMENTS AND APPLICATIONS[*]

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Abstract

The CPHS (Compact Pulsed Hadron Source) linac at Tsinghua University, is now in operation as an achievement of its mid-term objective. The 3 MeV proton beam with the peak current of 22 mA, pulse length of 100 μs, and repetition rate of 20 Hz has been delivered to the Beryllium target to produce the neutron beam from the year of 2013. We present in this paper the development and application of the high current linac, together with the measurement of the proton and neutron beams. The beam energy of the CPHS linac will be enhanced to 13 MeV after the DTL is ready in 2015.

INTRODUCTION

The CPHS (Compact Pulsed Hadron Source) project, which is aimed at becoming an experimental platform for education, research, and innovative applications at Tsinghua University, was launched in the year of 2009 [1]. The facility will provide the proton beam, together with the neutron beam by delivering the proton beam to bombard the Beryllium target. The designed parameters for the proton beam is 13 MeV/50 mA with the pulse length of 500 μs and repetition rate of 50 Hz. The ECR source produces the 50 keV proton beam followed by the LEBT which matches the beam into the downstream RFQ accelerator. The RFQ accelerates the beam to 3 MeV. The Alvarez-type DTL will accelerate the beam from 3 MeV to 13 MeV. The beam is matched to the DTL directly and there is no MEBT between the RFQ and DTL. The HEBT transports the beam from the DTL to the neutron target station. One uniform round beam spot on the Beryllium target is expected with the diameter of 5 cm [2]. The facility has achieved its mid-term objective in 2013. In this paper, the development status of the CPHS linac is presented, including the proton/neutron beam measurement and application performed.

OPERATION STATUS OF THE HIGH CURRENT 3MeV LINAC

On March 2013, the maximum transmission of the RFQ accelerator has reached 88% at 50 μs (pulse duration) /50 Hz (repetition frequency) during the commissioning [3][4]. On July 2013 the CPHS facility has achieved its mid-term objective: delivering the 3 MeV proton beam to bombard the Beryllium target [5]. As shown in Fig. 1, the 3 MeV proton beam is delivered directly from the RFQ output to the neutron target station by the HEBT. Five quadrupoles have been positioned instead of the DTL. The DTL will be ready in 2015 and the beam energy of the linac will be enhanced to 13 MeV.

Though the DTL is still in development, the CPHS facility has been in operation with the 3 MeV proton beam from 2013 until now, as shown in Fig. 2 and 3. The output current of the RFQ is relatively stable (30 mA) near the end of 2013. The total operation time in 2014 is estimated to be 500 hrs. With a reduction of the RF power of the ECR source, the peak current of the proton beam before the target has decreased to 20 mA in 2014. During the experiments which need only the proton beam, the beam is not bended by 90° and does not bombard the target.

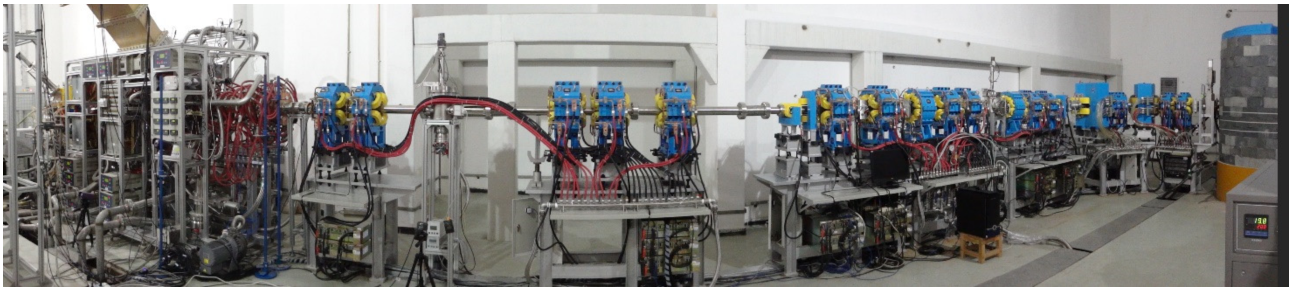

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Figure 1: Wide-angle view of the CPHS facility (from the ECR proton source to the neutron target station).

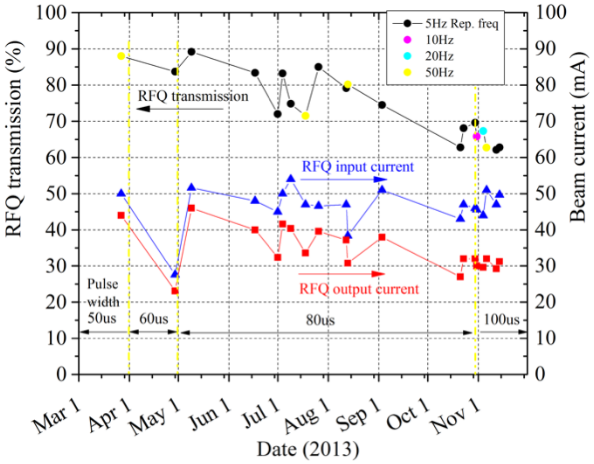

Figure 2: Operation history of the 3 MeV linac in 2013.

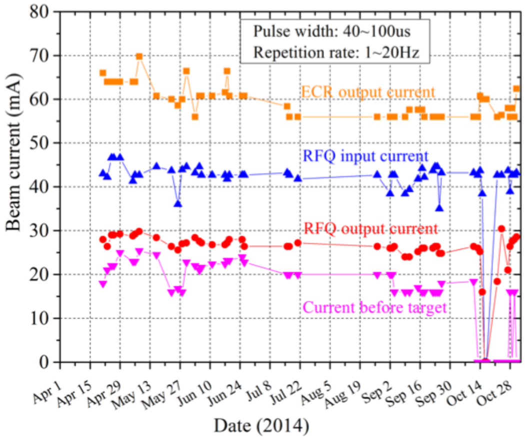

Figure 3: Operation history of the 3 MeV linac in 2014.

In 2015, the CPHS linac is aimed at reaching its designed performance, and stable operation. At the same time it will provide the proton and neutron beams to the users.

2D PROFILE MEASUREMENT OF THE PROTON BEAM

Based on the CT algorithm, 2D profile measurement of the proton beam is under development by the rotatable multi-wires [6]. Twenty carbon wires with the diameter of 30 µm are aligned and mounted on one board, as shown in Fig. 4. The electronics system for the measurement of the twenty wires simultaneously will be ready at the end of this year. Therefore only one wire is moved and rotated in the recent experiment and much more time is needed to finish the measurement. The first result is given in Fig. 4. The primary experiment shows that the beam is asymmetric at the measurement position and wire current near the beam centre is 0.14 mA (while the estimated value is 0.16 mA). The following challenging work on the electronics system is to measure the current which is less than 1 nA near the beam edge.

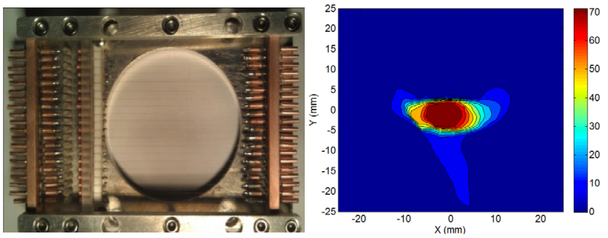

Figure 4: Rotatable multi-wires (left) and the first measurement result by only one wire (right).

MEASUREMENT OF THE NEUTRON BEAM

The neutrons are produced by the protons bombarding the Beryllium target. The Beryllium sheet has a thickness of 1.3 mm. Presently it is modified to be mounted on one Aluminium plate after it has broken twice with the original design with the operation repetition rate of 50 Hz. Fig. 5 shows the two sides of the Beryllium target with its original design (one side is in the vacuum and bombarded by the protons and the other side is cooled by the water), from which one crack can be observed clearly at the vacuum side.

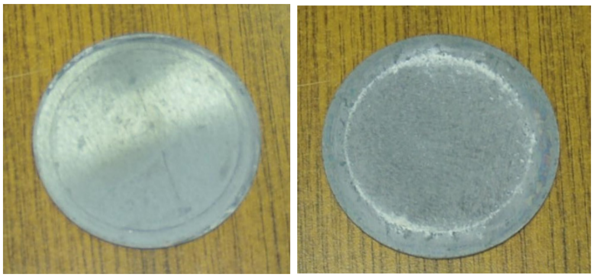

Figure 5: The vacuum side (left) and water side (right) of the Beryllium target.

Four neutron beam lines are planned in the CPHS project, among which two lines have been constructed: the neutron beam test line and neutron imaging line, as shown in Fig. 6.

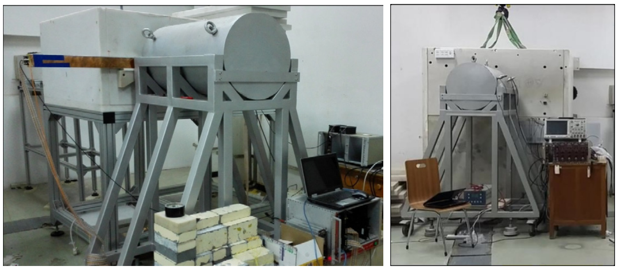

Figure 6: Neutron beam test line (left) and neutron imaging line (right).

The characteristics of the neutron beam has been measured on the test line. The wavelength spectrum of the thermal neutron is shown in Fig. 7, which agrees with the simulated value within ±15%. The time structure of the

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neutron with the wavelength of 1.17 Å is measured by the time-of-flight method, as shown in Fig. 8.

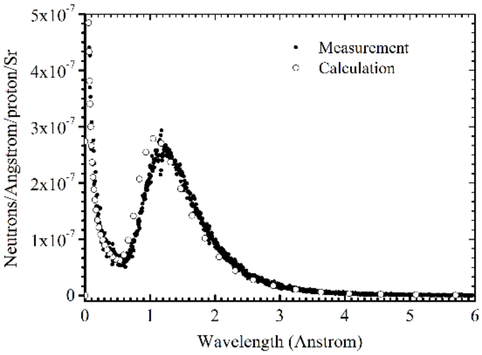

Figure 7: The wavelength spectrum of the first neutron production.

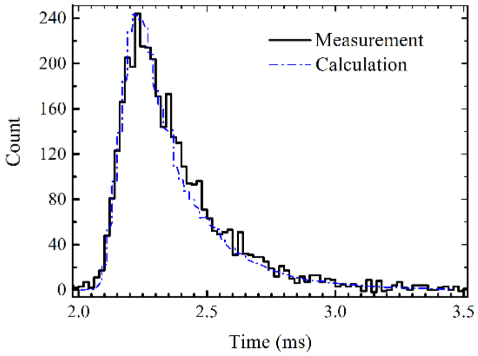

Figure 8: The time structure of the neutron with the wavelength of 1.17 Å.

NEUTRON APPLICATION

The operation time of the CPHS facility in 2014 is estimated to be 500 hrs. More than half of the operation time is occupied by the development of neutron detectors and neutron imaging, as shown in Fig. 9.

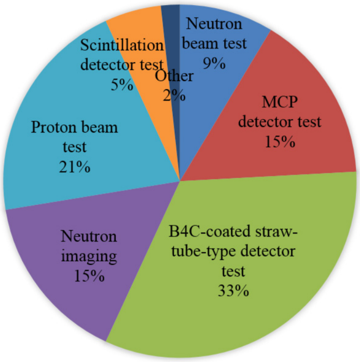

Figure 9: Time percentage of the CPHS operation for different application of the proton and neutron beam at Tsinghua University.

Neutron Detector Development

Two kinds of the neutron detectors are developed at Tsinghua University, the B_4C-coated straw-tube and gadolinium-doped Micro-Channel Plate (MCP), as shown in Fig. 10. The test performed on the neutron line of CPHS shows that the sensitive length of the straw-tube-type detector is longer than 1000 mm. The resolution of the tube module is 4 mm in the radial direction and better than 8 mm in the axial direction. The detection efficiency of the thermal neutron for single tube is larger than 7% (at 25.3 meV).

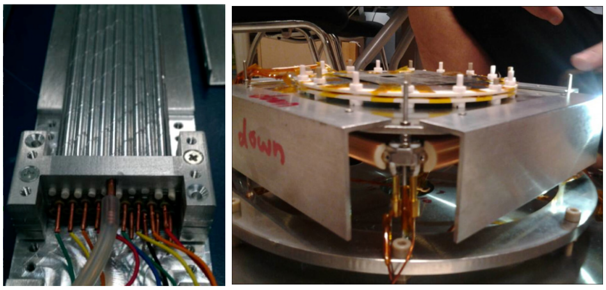

Figure 10: One B_4C-coated Straw-tube module (left) and one gadolinium-doped micro-channel plate (right).

Neutron Imaging

The imaging IP board is positioned at the end of the neutron beam line. The imaging result (Fig. 11) shows that the alignment of the beam line is good because the efficient scattered neutrons are reduced sufficiently. The contribution of the gamma ray is relatively low. The picture in Fig. 11 shows that the transverse distribution of the neutron beam is rather uniform.

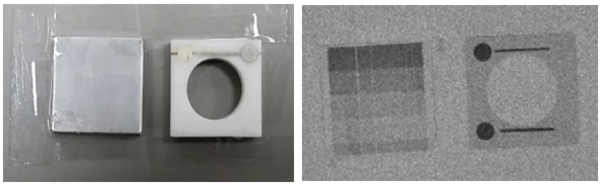

Figure 11: The test piece (left) and neutron imaging (right) after 10 hrs at the end of the neutron beam line.

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