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Status report of CPHS and neutron activities at Tsinghua University

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Summary. — The Compact Pulsed Hadron Source (CPHS) project that was launched in September 2009 at Tsinghua University has reached a first commissioning stage in conjunction with ongoing activities to fulfill the eventual design goal of a $\sim 10^{13}$ n/s epithermal-to-cold neutron yield for education, instrumentation development, and industrial applications. Here, we report the latest progress on the commissioning and applications of 3 MeV proton and neutron beam lines in the last one and half years, and the design, fabrication, engineering of the 13 MeV/16 kW proton accelerator system.

PACS 29.25.Dz – Neutron sources.
PACS 87.56.bd – Accelerators.

1. – Status of CPHS facility in 2014

The Compact Pulsed Hadron Source (CPHS) [1-3] with 3 MeV RFQ had operated for about 500 hours in 2014. The applications are shown in fig. 1. About half of the operation was for testing of two prototypes of neutron detectors under development, quarter of that was for neutronics performance measurement and neutron imaging beam line evaluation, and the other quarter was for 2D profile measurement of the proton beam with rotatable multiwires.

The transmission rate of the 3 MeV RFQ decreased from the highest record of 88% in March 2013 to 65% at the end of 2013. The RFQ linac operated with transmission rate of about 65%, beam energy of 3 MeV, peak current of 26 mA, pulse duration of 100 μs and repetition rate of 20 Hz in 2014, as shown in fig. 2.

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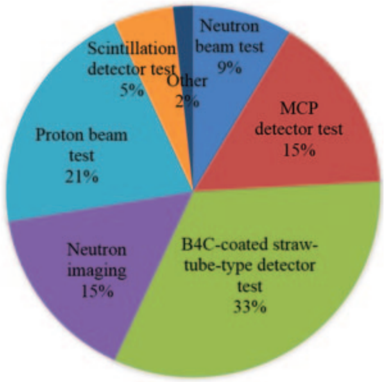

Fig. 1. – The applications of CPHS operation in 2014.

In order to solve the transmission rate degradation, from the end of 2014 to June 2015, the RFQ was re-aligned. The field distribution inside the RFQ cavity was re-checked, and the field tuning was performed and the relative error of the quadrupole field was reduced from 7.3% to 2.6%. The beam emittance at the entrance of the RFQ was measured and re-commissioned. Finally, the transmission rate of the RFQ went back to 91% by the end of 2015.

The CPHS-DTL is under development with ten test drift tubes (five aluminum tubes and five copper ones) fabricated. It is expected to start the formal manufacture early 2016 and start the installation of the DTL by the end of 2016.

Neutrons were produced by proton beam bombarding the 1.2 mm Be target. The Be target was re-designed to be mounted on a 2 mm Al plate since it had broken twice after only several hours or several days operation on the repetition rate of 50 Hz. The main reason of the crack was evaluated to came from the thermal stress under high operation repetition rate. The new target with Al plate mounted had worked well in 2014 with the repetition rate of 20 Hz. Increasing the repetition rate to 50 Hz to test the new target with 3 MeV proton beam will be done in the future.

Measurements of the neutronics performance of CPHS was accomplished with the target station group of the China Spallation Neutron Source (CSNS), as shown in fig. 3.

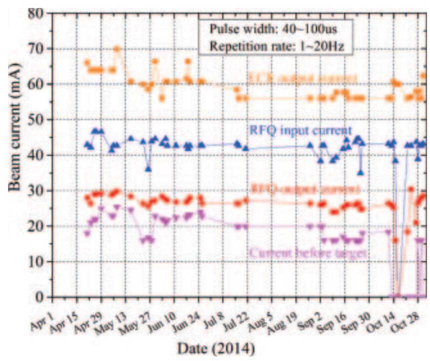

Fig. 2. – Operation status of CPHS-RFQ in 2014.

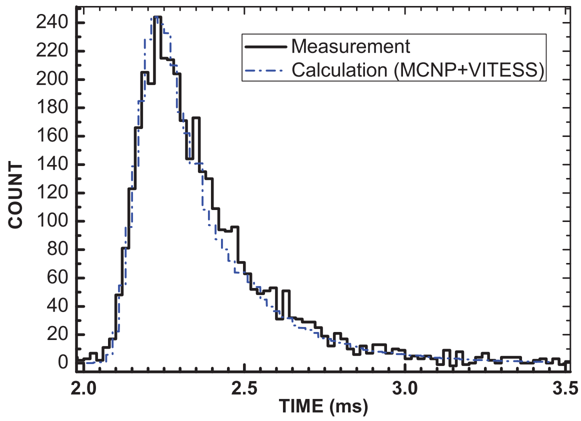

Fig. 3. – Pulse shape of 1.1696 Å neutron measured and simulated at CPHS.

2. – Imaging station

The imaging station with a commercial neutron imaging plate (IP) system (by Fuji) adopts the conventional single-hole geometry. Some neutron imaging experiments were done to preliminarily verify the performance of the source and the imaging beam line.

The IP and ASTM standard Image Quality Indicators (IQI, fig. 4 (left)) were set together at positions P1 and P2 respectively along the imaging beam line. P1 is at the boundary of TMR shield, at 1 meter to the moderator, and without any collimation. P2 is 5 meters to the moderator, and flying tubes and collimators were built.

The neutron image of Beam Purity Indicator (BPI) was achieved at P1 with 30 minutes exposed, as shown in fig. 4 (middle). The neutron image of BPI and Sensitivity Indicator (SI) was achieved at P2 with 10 hours exposed, as shown in fig. 4 (right).

The PSL values of selected positions in the BPI images at P1 and P2 were measured by software to calculate the effective thermal neutron content(NC), effective scattered neutron content(S), effective gamma content(γ) and effective pair production content(P). It is shown the scattered neutrons were sufficiently reduced by collimation since S at P2 is much low than S at P1. The contribution of gamma ray was relatively low as shown by γ value at P1 and P2, and it is also shown the transverse distribution of the neutron beam was rather uniform.

Fig. 4. – Image Quality Indicator (left) and the neutron image at P1 (middle) and at P2 (right).

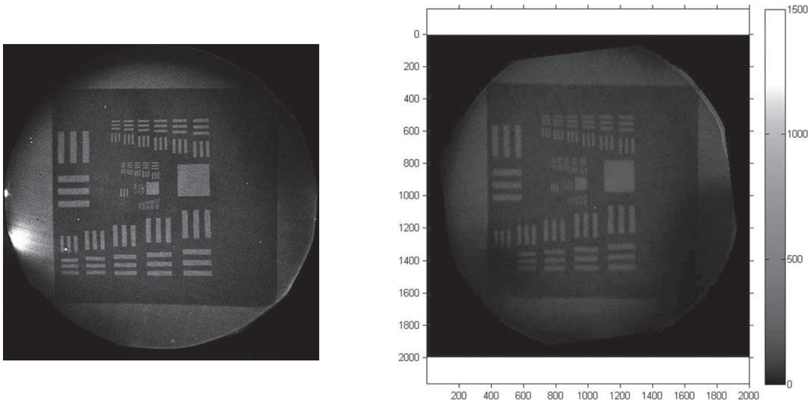

Fig. 5. – the MCP image of a USAF-1951 Gd-mask measured with the beam line of CPHS (left) and CARR (right)

3. – Development of neutron detectors

Along with the commissioning of CPHS, two prototypes of neutron detectors based on micro-channel plate (MCP) and the boron-coated straw tube under development, were evaluated [4-9].

The neutron sensitive MCP detector was tested on the beam line of thermal neutron at the imaging beam line of CPHS and the test beam line of China Advanced Research Reactor (CARR). The spatial resolution of thermal neutron image is estimated as 88 μm. And the detection efficiency of thermal neutron is over 30%@25.3 meV. Neutron images of the USAF-1951 Gd-mask achieved with MCP at CPHS and CARR, respectively, are shown in fig. 5.

The prototype of the boron-coated straw tube detector module consists of 40 straw tubes in 4 rows and 10 columns. Each straw tube is 1m in length and 4 mm in diameter. A readout electronics system based on charge distribution readout method was developed. The front end electronics was embedded inside the two ends of the detector module to reduce noise. The average spatial resolution of $4 \times 4 \times 6.8\,\text{mm}^3$ was achieved at the test beam line of CPHS.

A new prototype with straw tube diameter of 8 mm and sensitive area of 800 mm $\times$ 800 mm is under development to build the CPHS SANS with boron-coated straw tube array neutron detector.

4. – Research on neutron optics special for small neutron source

Axisymmetric grazing-incidence neutron focusing optics were proposed by researchers from MIT recently [10] and it is expected to meet the challenge of extremely low neutron flux of the compact neutron sources such as CPHS. A preliminary study of CPHS-SANS with focusing mirror had been carried out [11], and three types of focusing mirrors, including ellipsoid, paraboloid-paraboloid, and ellipsoid-hyperboloid, were taken into account to increase neutron intensity and improve Q_{min}.

Coaxial confocal mirrors with different radii can be nested together to increase the neutron collection efficiency but accompanying by larger sample required. It is shown by simulation that neutron intensity could be improved by 80 times than the traditional pinhole design [12] when the radius of samples is less than 2 cm. It is expected to solve the fabrication of the mirrors through the cooperation with Tongji University, who has lots of experience on X-ray focusing mirrors, and of course a number of improvements on design and fabrication should be implemented in the future.

5. – Conclusion

In summary, the delivery of 3 MeV proton beam and neutron generation in mid-2013 and the first year operation and applications in 2014 had been achieved at CPHS. Activities are continuing for the completion of the DTL (in 2016) and for the construction of the small-angle neutron scattering (SANS) instrument in conjunction with the 13 MeV proton plus cold-neutron operation in the future. It is also expected neutron detectors, neutron optics and some other technologies on neutron instrumentation will be developed accompany with the construction and operation of CPHS at Tsinghua University.

REFERENCES

[1] Loong C. K., Wei J., Guan X. L. and Wang X. W., *Phys. Proc.*, **26** (2002) 8.
[2] Wang X., Loong C.-K., Guan X. and Du T., *Phys. Proc.*, **60** (2014) 97.
[3] Wang X., Xing Q., Loong C.-K., Guan X. and Du T., *Phys. Proc.*, **60** (2014) 186.
[4] Pan J., Yang Y. and Tian Y., *J. Instrum.*, **8** (2013) P01015.
[5] Yang Tian, Yi-gang Yang and Jing-sheng Pan, *Chin. Phys. C*, **38** (2014) 086003.
[6] Wang Yiming, Yang Yigang and Wang Xuewu, *Nucl. Instrum. Methods Phys. Res. A*, **784** (2015) 226.
[7] Chen C. *et al.*, *Study of boron-lined straw-tube detector array for neutron scattering measurement*, in *IEEE Nuclear Science Symposium Conference* Record. 2012: 176–179.
[8] Yu H. *et al.*, *Study of delay-line readout for boron coated straw detector*, in *IEEE Nuclear Science Symposium and Medical Imaging Conference*, 2013.
[9] Chen C. *et al.*, *Realization and test of position sensitive boron coated straw-tube*, in *IEEE Nuclear Science Symposium and Medical Imaging Conference*, 2013.
[10] Boris Khaykovich *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **631** (2011) 98.
[11] Wu Huarui *et al.*, *Preliminary study of SANS with focusing mirrors at CPHS*, in *Proceedings of the 21st Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-XXI), JAEA-Conf.* 2015-002, pp. 349-355.
[12] Huang T. C., Gong H., Shao B. B. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **669** (2012) 14.