Development of Transportable Accelerator-Driven Neutron Source in XJTU

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1. Introduction

Neutrons have been widely used in many applications, such as Boron Neutron Capture Therapy (BNCT), neutron imaging, neutron scattering research, and so on [1]. Due to the low cost, small size, short construction time, and acceptable neutron yield for many purposes, the development of Compact Accelerator-driven Neutron Source (CANS) technology has progressed worldwide in recent years. And outdoor neutron non-destructive testing is likely to be realized by developing a Transportable Accelerator-driven Neutron Source (TANS) based on existing CANS facilities for some specific situations, like bridge and road detection. The project of TANS in Xi'an Jiaotong University (XJTU) has been carried out. The progress about compact accelerator, target design, shielding structure and neutron backscattering radiography system is stated as follow. And the layout of every consistence is shown in Fig. 1.

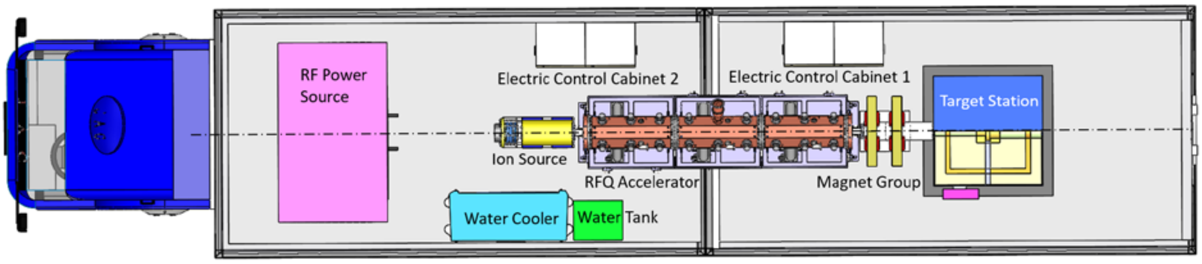


Fig. 1. Structure of the TANS.

2. RFQ accelerator

The four-vane RFQ accelerator has been adopted as its compact structure and high transmission efficiency. The whole accelerator system consists of RFQ cavity, RF power source, cooling machine, vacuum as well as generator. To reduce the costs and size of the accelerators system as much as possible, the working frequency of 325MHz has been selected with compromise between power consumption, cavity size and weight, as well as feasibility of construction. The RFQ was designed to accelerate the proton beam with peak current of 12mA to 2.5MeV in the acceleration efficiency above 93.2%. The RFQ length and weight were 2.6m and 1.5t, respectively. And the structure of RFQ accelerator for TANS is shown in Fig. 2.

3. Target design

We chose the ^{7}Li (p, n)^{7}Be reaction, in which lithium (Li) rather than beryllium (Be) was used as the target material due to its relatively higher neutron yield. Aiming at minimization on reduction in neutron attenuation and sufficient cooling, we proposed a new cooling configuration for a target featuring edge-cooling without flowing water in the back side to be applicable for TANS, which is shown in Fig.3. Based on the simulation by Monte Carle code and finite element method software, the effect on neutron attenuation and cooling effect have been evaluated, and the structure and size are optimized.

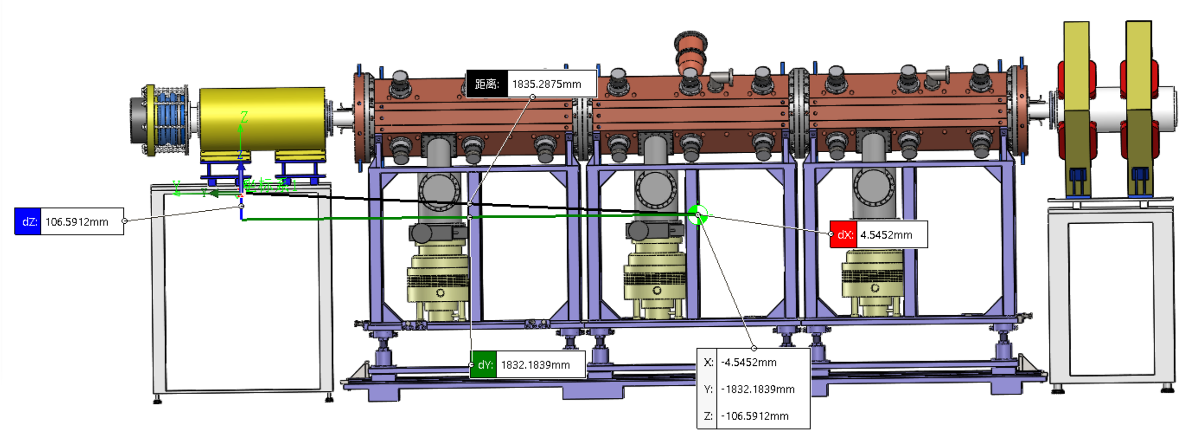


Fig. 2. Structure of RAQ accelerator for TANS.

Table.1. Parameter of RFQ accelerator for TANS

Frequency [MHz]	325
Beam current [mA]	12
W_{out} [MeV]	2.5
Input Nor. Rms emit. [mm·mrad]	0.10
Inter-vane voltage [kV]	65
Max. modulation	2.49
Max. phase [deg]	-19.0
Peak electric field [MV/m]	24.03
Kp factor	1.35
Electrode length [m]	
Average aperture [mm]	3.746
Minimal aperture [mm]	2.01
Trans. (PARMTEQM) [%]	98.1
Acc (PARMTEQM) [%]	93.2

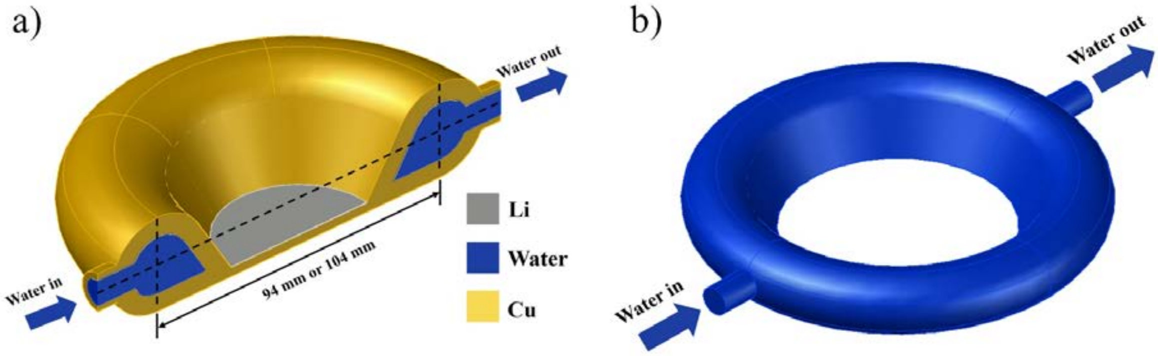


Fig. 3. Edge-cooling target: (a) vertical cross section; (b) perspective drawing to show the cooling water flowing.

4. Shielding structure

We optimized the reflector and the shielding design of the target station for TANS. A high-performance reflector material was selected by comparing a number of candidates, which aimed at enhancing the fast neutron intensity for the non-destructive testing. A compact and light-weight shielding design was optimized through a multi-objective optimization way based on NSGA-MC [2]. The target station of TANS is shown in Fig. 4.

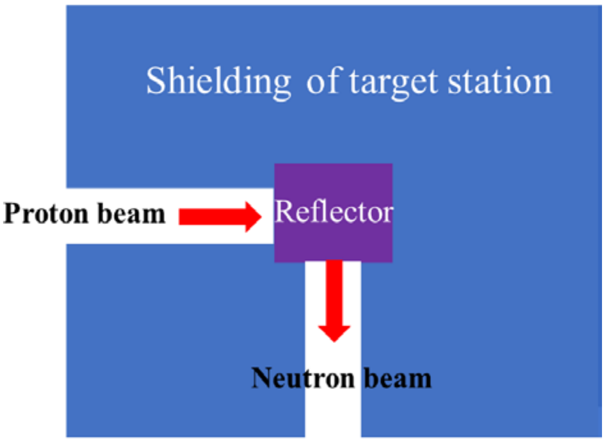
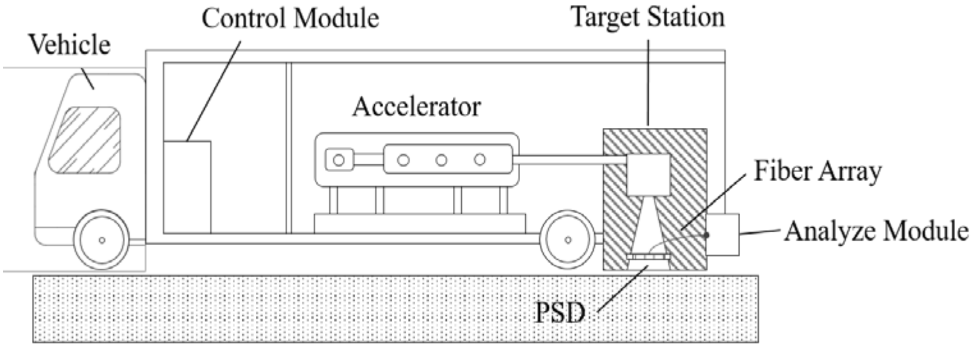


Fig. 4. Shielding structure of TANS

5. Neutron Backscattering Radiography System Based on TANS

TANS is a potential tool for infrastructure NDT, while the neutron backscattering radiography (NBR) is almost the only way to apply that. Our group has been committed to the development of TANS, and make important breakthroughs in key systems. Upper picture of Fig. 5 shows the structure of TANS backscattering radiography system. The source uses 2.5MeV proton and solid lithium target. Bottom picture of Fig. 5 shows energy spectrum of the neutron source.



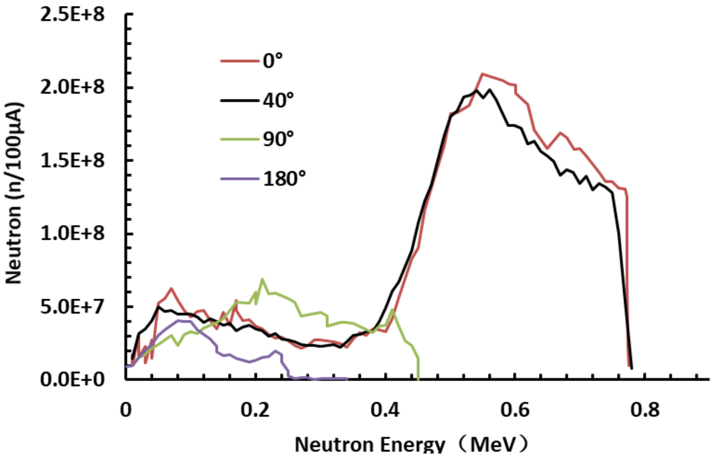


Fig. 5. Structure of TANS NBR system. Upper picture –system structure, bottom picture – energy spectrum.

NBR can effectively distinguish the defects, especially void and water gap. Fig. 6 shows the simulation results of defects detection. Defects depth is 10cm, size is 5×5×5cm. Detector size is 30px×30px, pixel size is 0.5cm. Water can reflect more thermal neutron than other material, while void can hardly reflect neutron, thus, NBR can distinguish void and water by means of backscattering neutron flux and energy.

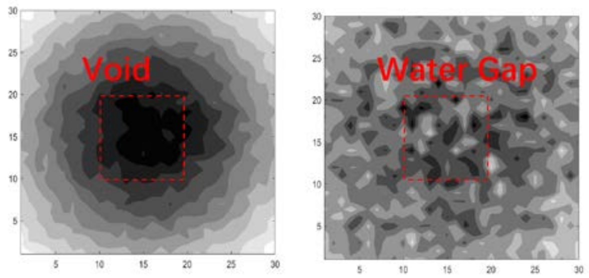


Fig. 6. NBR simulation of void and water defects.

References

[1] L. Xu, W. Schultz, C.Huiszoon, Petrophysics 51(3), 184 (2010).

[2] Ma B., Song L., Yan M., et al., Multi-objective Optimization Shielding Design for Compact Accelerator-driven Neutron Sources by Application of NSGA-II and MCNP[J].IEEE Transactions on Nuclear Science, 2020, PP(99):1-1.