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DESIGN AND PROGRAMMING OF A MULTIFUNCTIONAL DEVICE FOR ACCELERATOR BEAM PROFILE MEASUREMENT AND BEAM STOP*

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Abstract

During the pre-research phase of China Spallation Neutron Source (CSNS) upgrade project (CSNS-II), in order to conduct beam commissioning of the Radio Frequency Quadrupole (RFQ) under high-intensity beam conditions, the structure of the last-stage wire scanner of the Medium Energy Beam Transport (MEBT) was innovatively modified. This modification not only added a Beam Stop but also significantly enhanced the efficiency of wire scanner. This paper presents the architecture and operational programming of a novel multifunctional device designed for accelerator beam diagnostics and beam termination: beam profile measurement via advanced sensing mechanisms and Beam Stop using a braided carbon fiber plate as the primary beam stop.

INTRUDUCTION

The China Spallation Neutron Source (CSNS) [1] is a large-scale scientific facility in China and stands as a vital platform for advancing scientific research and industrial innovation. Its primary mission is to generate intense pulsed neutron beams, which serve as a "super microscope" enabling researchers to explore the microscopic structure and dynamic processes of materials across diverse fields.

The accelerator system of CSNS complex consists of a 50 keV H- ion source, a 3 MeV radio frequency quadrupole (RFQ), an 80 MeV drift tube linac (DTL), a 1.6 GeV rapid-cycling synchrotron (RCS) and several beam lines. The Medium Energy Beam Transport (MEBT) [2] section of CSNS plays a vital role in beam transport and parameter adjustment. As depicted in Fig. 1, which show cases the structure of the MEBT section equipment, the traditional MEBTWS04 has shortcomings in function, Carbon nanotubes are applied as a new wire material and studied in comparison with carbon fiber wires.

Before the upgrade, the CSNS had a designed beam power of 100 kW. However, through continuous efforts and recent upgrades, the beam power had already reached 170 kW. With the Phase II upgrade, the proton beam power is expected to 500 kW. This significant increase in power means that the CSNS will be able to generate a far more intense pulsed neutron beam. The goal is concretely realized through a significant leap in beam current specifically, increasing the beam current from the pre-upgrade 15 mA to the target 50 mA with a repetition frequency of 25 Hz with a pulse width of 560 µs. The beam parameter is described in Table 1.

Table 1: Main Parameters of CSNS

Project Phase	I	II
Beam Power	100kW	500kW
Energy	1.6GeV	1.6GeV
Beam Current	15-20 mA	50mA
Pulse Length	560us	560us
RF Frequency	324MHz	324MHz
Repetition Frequency	25Hz	25Hz

During the pre-research phase of CSNS-II, it is intended to conduct a series of experiments on the ion source and RFQ. However, the beam quality of the accelerator remains relatively poor at this stage. If such a low-quality beam directly enters the DTL cavity, it will cause certain damage to the cavity. Notably, the DTL cavity is a delicate component with high maintenance costs. To protect the DTL cavity, a baffle is proposed to be installed at the end of the Medium Energy Beam Transport (MEBT) section. This baffle will block the beam from entering the DTL during the beam commissioning process of the ion source and RFQ. Nevertheless, the current MEBT section features a compact structure, leaving no extra space for installing an additional Faraday cup. Therefore, a decision has been made to modify the MEBTWS04 device located at the end of the MEBT section. The modified MEBTWS04 is expected to not only retain its original function of beam profile measurement but also serve as a beam baffle.

Additionally, in depth research on the impact of new materials on the beam is necessary. This paper concentrates on the transformation of the WS in the MEBT section [3] of CSNS into a multifunctional device featuring double wires and a baffle. Carbon nanotubes are utilized as the wire material, and carbon fiber is employed for the baffle. A crossed double-wire structure, which enables simultaneous measurement of horizontal and vertical beam profiles, has replaced the original three-wire structure that only supported unidirectional measurement. The wire oriented at the 45° direction—with a relatively low utilization rate—has been removed. With the new structure, measurements for both horizontal and vertical positions can be acquired by moving the structure to one single position, thereby improving the scanning efficiency. The influence of the high

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outgassing rate of carbon nanotubes and carbon fiber baffles on the beam during initial use is investigated, and beam parameters are measured and analyzed using the transformed equipment.

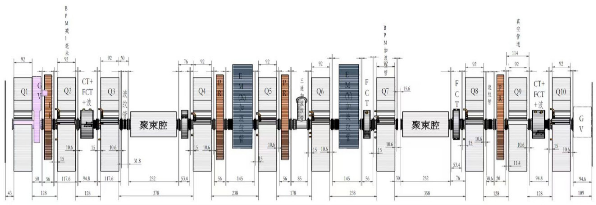

Figure 1: CSNS MEBT layout.

EQUIPMENT TRANSFORMATION

Figures 2 and 3 illustrate the structural evolution of the Wire Scanner (MEBTWS04), which is utilized for measuring the accelerator beam profile . the original three-wire [4] joint structure is changed to modified crossed double-wire structure with the wires spacing of approximately 5 mm, Moreover, a carbon fiber baffle is added in the new structure, which can intercept the beam during the debugging of the radio-frequency cavity to avoid damage to subsequent cavities such as the DTL, greatly improves the measurement efficiency, enhances the protection of downstream components.

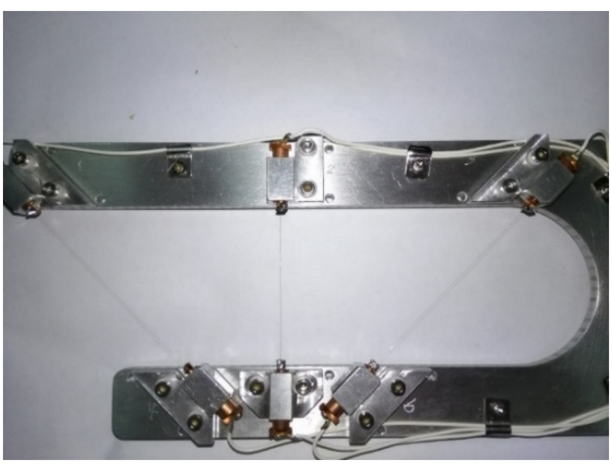

Figure 2: The original three-wire joint structure.

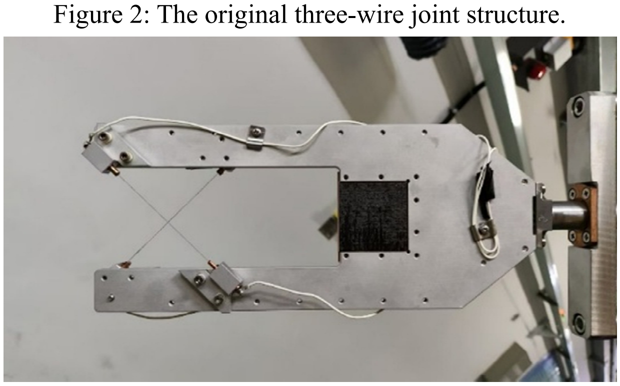

Figure 3: The new wore scanner of double-crossed wire structure and a carbon fiber baffle.

Carbon nanotubes are chosen as the wire material. Carbon nanotubes have excellent mechanical and electrical properties, which can improve the precision of beam detection. However, the outgassing rate of carbon nanotubes is high at the initial stage. Therefore, a pre-treatment process is adopted: the carbon nanotubes are baked in a low - vacuum environment for a certain period to accelerate the gas release and stabilize the outgassing rate.

Carbon fiber is used as the baffle material adopts a woven structure to avoid outgassing caused by adhesive problems. Although its outgassing rate is always high, it has good mechanical properties and high-temperature resistance, which can withstand the impact of the beam. It is mainly used for beam adjustment at the front-end ion source, where the vacuum requirement is relatively low compared with the rear end.

BEAM STUDY

When the beam passes through the double carbon nanotube wires, induced currents or charges are generated on the wires. By measuring these electrical signals, beam parameters such as position, intensity, and profile can be obtained. For example, the center positions of the beam in the X and Y directions can be calculated based on the magnitude and time difference of the induced signals on the two wires. The measurement interface of the CSNS MEBT Wire Scanner is shown in Fig. 4.

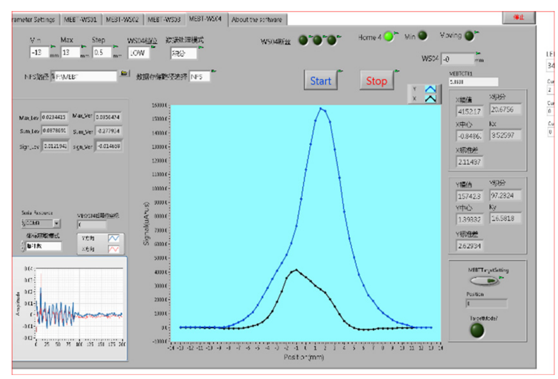

Figure 4: MEBTWS04 work in a beam with, a repetition frequency of 1 Hz, a pulse width of 50 µs, and a current intensity of 10 mA.

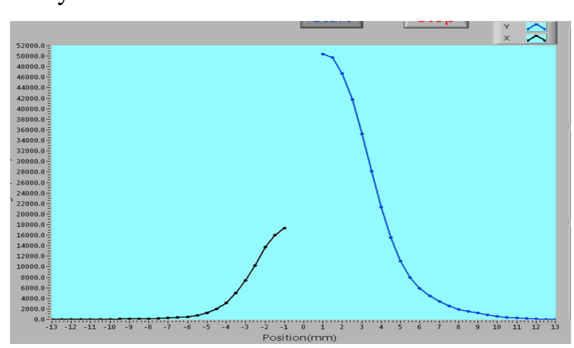

Figure 5: MEBTWS04 work in a beam with, a repetition frequency of 1 Hz, a pulse width of 100 µs, and a current intensity of 10 mA.

Initially, the new wire scanner MEBTWS04 operates under a beam with a repetition frequency of 1 Hz, a pulse

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width of 50 μs, and a current intensity of 10 mA. When the double wires run to the center of the beam pipe, it triggers a vacuum alarm but does not cause beam pulling. However, when operating under a beam with a repetition frequency of 1 Hz, a pulse width of 100 μs, and a current intensity of 10 mA, beam pulling occurs when the double wires reach the centre of the beam pipe, mainly due to outgassing from carbon nanotubes bombarded by the beam as shown in Fig. 5. After a period of use and beam baking, beam pulling no longer happens even under the beam conditions of 1 Hz repetition frequency, 100 μs pulse width, and 10 mA current intensity. Another phenomenon is that the amplitude of the induction signals of the XY double wires is different, resulting in significant differences in the obtained horizontal and vertical profiles.

Regarding the beam baffle, it can currently only be used in single mode and cannot be used under continuous beam conditions.

Although the transformation of the equipment and the research on beam parameters have achieved certain results, there are still some problems to be solved. For example, the outgassing rate of carbon nanotubes still needs to be further reduced to minimize the impact on the beam. The structure of the carbon fiber baffle can also be optimized to improve its performance in a vacuum environment. In addition, the signal processing algorithm can be further optimized to improve the measurement accuracy of beam parameters

CONCLUSION

The transformation of the CSNS MEBTWS04 into a multifunctional device with double crossed carbon nanotube wires and a carbon fiber baffle is feasible. In addition to fulfilling the functional requirements, the new structure of MEBTWS04 has also significantly enhanced the scanning efficiency. Through the study of beam parameters and the influence of outgassing rate, the performance of the equipment is optimized, which provides a reliable basis for the second stage research of CSNS. In the future, further research can be carried out on material improvement and equipment structure optimization to further improve the performance of the device.

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