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STUDY ON THE IMPORTANT TECHNOLOGIES OF 300 MeV UPGRADE FOR THE CSNS INJECTION SYSTEM*

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Abstract

The China Spallation Neutron Source (CSNS-I) have achieved the design goal of 100kW beam power on the target in Feb., 2020. As the second phase of the CSNS, CSNS-II will achieve a beam power on the target of 500 kW. The injection energy of CSNS-II will be increased from 80 MeV to 300 MeV and the average beam current of the Linac will increase 5 times. Therefore, the injection system will require a complete upgrade. In this paper, the design scheme of the injection system for CSNS-II will be introduced. The key technologies of the upgrade injection system will be carefully analyzed and pre-developed, such as the pulse power supplies and their magnets, the special-shaped ceramic vacuum chambers, the main stripping foil, the stripped electron collection, and so on.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a multidisciplinary platform [1, 2] and have achieved the design goal of 100kW beam power on the target in Feb., 2020. Its accelerator consists of an 80 MeV H^- Linac and a 1.6 GeV rapid cycling synchrotron (RCS) with a repetition rate of 25 Hz which accumulates an 80 MeV injection beam, accelerates the beam to the design energy of 1.6 GeV and extracts the high energy beam to the target [3, 4].

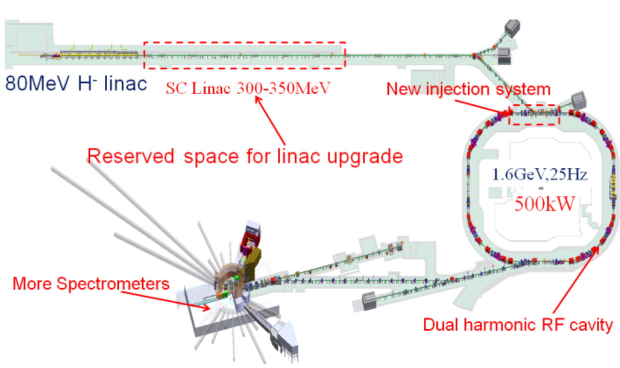

Figure 1: Layout of CSNS-II.

To improve the beam power on the target from 100 kW to 500 kW, the accelerator needs to be upgraded, including the Linac upgrade, the injection system upgrade, and new Magnetic Alloy dual-harmonic cavities [5]. Figure 1 shows the layout of CSNS-II. It can be seen that the injection system upgrade is an important part of CSNS-II. Table 1 shows the comparison of the main accelerator beam parameters between CSNS-I and CSNS-II. It can be seen that: the Linac energy will increase from 80 MeV to 300 MeV; the average beam current of the Linac will increase 5 times; the injection beam power will be raised to nearly 20 times. Therefore, the injection system requires a complete upgrade.

Table 1: Comparison of the Main Accelerator Beam Parameters between CSNS-I and CSNS-II

Phase	CSNS-I	CSNS-II
Beam power on the target (kW)	100	500
Linac energy (GeV)	0.08	0.3
Extraction beam energy (GeV)	1.6	1.6
Average beam current (μA)	62.5	312.5
Repetition (Hz)	50	50
Protons per pulse (10^{13})	1.56	7.8
Ion Source type	Penning	RF Vol.

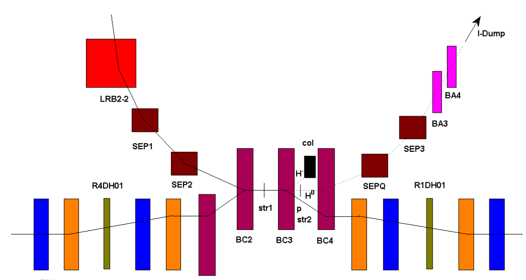

Figure 2: Layout of the upgrade injection system for CSNS-II.

Based on the injection system design of CSNS-I [6], after in-depth research and schemes comparison, an optimized upgrade scheme of the injection system is given for CSNS-II. Figure 2 shows the layout of the new injection system for CSNS-II. It can be found that many new equipments and hardware will be added and replaced in the injection region. Therefore, some key technologies

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for the upgrade injection system should be carefully studied and pre-developed, such as the pulse power supplies and their magnets, the special-shaped ceramic vacuum chambers, the main stripping foil, the stripped electron collection, and so on.

PULSE POWER SUPPLIES AND THEIR MAGNETS

Based on the theoretical analysis and calculation, the direct current (DC) magnets (BC1-BC4) of the horizontal chicane bump in the injection region can break the symmetry of the RCS and have a great influence on the beam dynamics of the RCS. The simulation results also confirmed that, compared to the alternating current (AC) magnets, these DC magnets (BC1-BC4) can result in serious emittance growth. Figure 3 shows the 99% emittance evolution for the horizontal chicane bump with DC and AC magnets. Therefore, for the new injection system of CSNS-II, the four DC magnets may need to be changed to the AC magnets and their power supply also need to be replaced with a pulse power supply.

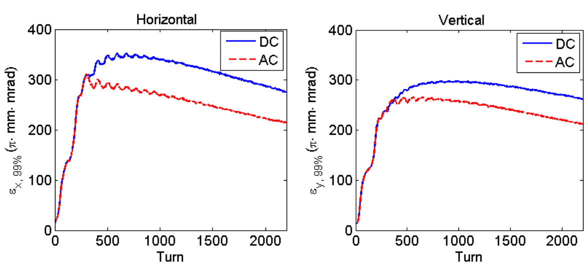

Figure 3: The 99% emittance evolution for the horizontal chicane bump with DC and AC magnets.

Table 2: Design Parameters of the Magnets and Power Supplies in the Injection Region

	BL 80 MeV (CSNS-I)	I 80 MeV (CSNS-I)	BL 300 MeV (CSNS-II)	I 300 MeV (CSNS-II)
BH	0.0345 T·m	9000A	0.077 T·m	19752A
BV	0.0243 T·m	6500A	0.050 T·m	13015A
BC	0.0844 T·m	490A	0.189 T·m	17926A

For the upgrade injection system of CSNS-II, there are three groups of pulse power supplies and magnets, including BC1-BC4 which generate a horizontal chicane bump, BH1-BH4 which are used for painting in the horizontal plane, BV1-BV4 which are used for painting in the vertical plane. In order to be suitable for the increased injection energy of CSNS-II, the design parameters of the magnets and power supplies in the injection region should also be increased. Table 2 shows the comparison of the design parameters of the magnets and power supplies in the injection region between CSNS-I and CSNS-II. It can be found that, compared to that of CSNS-I, the integrated field strengths and currents of all the magnets and power supplies will increase a lot. Therefore, some magnets and power supplies, such as BH, BV, BC, need to be replaced for the upgrade injection system. Furthermore, since the currents of the pulse power supplies will be more than 2 times higher than their originals, in order to make sure the mature technologies for the engineering application, it is highly necessary to pre-develop the key technologies of the high current pulse power supplies.

SPECIAL-SHAPED CERAMIC VACUUM CHAMBERS

For the upgrade injection system of CSNS-II, the four DC magnets (BC1-BC4) of the horizontal chicane bump may need to be changed to the alternating current (AC) magnets and their power supply also need to be replaced with a pulse power supply. In order to avoid the influence of the eddy current effect, the original stainless steel vacuum chambers need to be replaced by the ceramic vacuum chambers.

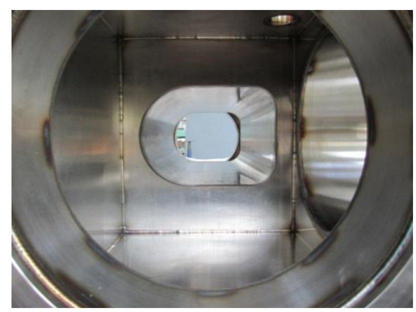

Figure 4: Inner cavity of BC special-shaped vacuum chamber.

Different from other regular-shaped ceramic vacuum chambers of the RCS, the ceramic vacuum chambers of the magnets BC1-BC4 have special shape, as shown in Fig. 4. Referring to the research experience of J-PARC on the special-shaped vacuum chamber [7, 8], if the ceramic material is used, the technology of the special-shaped vacuum chambers will be very difficult and the development time may be relatively long. Therefore, in order to make sure the mature technologies for the engineering application, it is necessary to pre-develop the key technologies of the special-shaped ceramic vacuum chambers.

MAIN STRIPPING FOIL

For CSNS-II, the Linac energy will increase from 80 MeV to 300 MeV and the average beam current of the Linac will increase 5 times. Then, the injection beam power will be raised to nearly 20 times. At the same time, due to the great increase of the injection beam pulse width, the average traversal number of the main stripping foil will also increase. Therefore, the temperature, service life and residual dose of the main stripping foil need to be carefully studied and optimized.

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For CSNS-I, the highest temperature of the main stripping foil is about 1400 K. However, for CSNS-II, the highest temperature of the main stripping foil will achieve about 3600 K which is relatively close to the melting point of the stripping foil material (HBC). Figure 5 shows the variation curve of the highest temperature of the main stripping foil in the injection process. Therefore, different materials of the stripping foil should be searched to meet the requirements of temperature rise. At the same time, a temperature measuring device for the stripping foil should be installed to monitor the actual temperature of the main stripping foil.

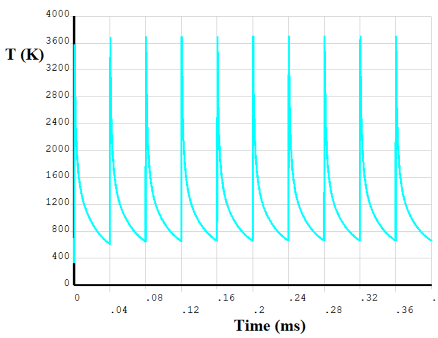

Figure 5: Variation curve of the highest temperature of the main stripping foil in the injection process.

According to the operation results of the CSNS accelerator, at the design beam power on the target of 100 kW, the service life of the main stripping foil is only 1.5 months. Due to the increase in the temperature and thickness, the service life of the main stripping foil for CSNS-II will be shorter. Therefore, the main stripping foils with different materials and structures need to be studied during the beam commissioning to provide more options for CSNS-II.

STRIPPED ELECTRON COLLECTION

For CSNS-I, due to the stripped electrons of small beam loss and low energy, they are not collected but hit directly to the vacuum chambers. However, for CSNS-II, the beam loss caused by the stripped electrons is very large and then these electrons need to be collected. Table 3 shows the beam loss caused by the stripped electrons. It can be found that the stripped electron beam loss of CSNS-II will be raised to nearly 20 times that of CSNS-I.

Table 3: Beam Loss Caused by the Stripped Electrons

Phase	CSNS-I	CSNS-II
Injection beam power (kW)	5	93.75
Foil thickness of Str-1 (μg/cm^2)	100	260
Stripping efficiency	99.7%	99.7%
Stripped electron beam loss (W)	5.4	101.7

Referring to the research experiences of SNS [9, 10] and J-PARC [11, 12] on the stripped electron collection, it is necessary to install an electron catcher near the main stripping foil. Figure 6 shows the reserved location for the electron catcher. Therefore, in order to make sure the mature technologies for the engineering application, it is necessary to pre-study the stripped electron collection scheme and the electron catcher.

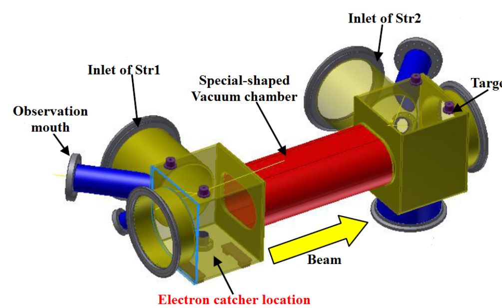

Figure 6: Reserved location for the electron catcher.

SUMMARY AND DISCUSSION

After the completion of the design goal of CSNS-I, the physics design of CSNS-II have began in a comprehensive way. The upgrade injection system is the core part of CSNS-II accelerator. In this paper, the design scheme of the injection system for CSNS-II have be introduced. The key technologies of the upgrade injection system have be carefully analyzed.

For the pulse power supplies, due to their currents will be more than 2 times higher than the originals, in order to make sure the mature technologies for the engineering application, it is highly necessary to pre-develop the key technologies. For the special-shaped ceramic vacuum chambers, their technology will be very difficult and the development time may be relatively long. For the main stripping foil, in order to improve the service life and meet the requirements of temperature rise, the foils with different materials and structures need to be studied in detail. In order to deal with the stripped electrons whose beam loss is very large for CSNS-II, the stripped electron collection scheme and electron catcher should be pre-studied.

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