DESIGN AND EXPERIMENTAL RESULTS OF AN ELECTRO-STATIC PRE-CHOPPER FOR CSNS LEBT*

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Abstract

The China Spallation Neutron Source (CSNS) front end incorporates a pre-chopper in the Low Energy Beam Transport line (LEBT) that will remove a 530 ns section of beam at approximately 1 MHz rate, which is the RF frequency of the ring at injection. It's one of the most critical devices for properly controlling the injecting beam loss. Physical designing of the pre-chopper is carried out, and the RFQ itself was used as the beam dump of the chopper system. In order to examine the reliability of the pre-chopper design, the beam study of a similar chopper system was successfully performed. Results of physical design and experiments will be presented.

INTRODUCTION

The China Spallation Neutron Source (CSNS) comprises an 80 MeV H linac injecting a 1.6-GeV rapid-cycling synchrotron (RCS) with 15 mA peak current [1]. To reduce the beam loss during the injection, a 530 ns notch is introduced in the injected beam by an electrostatic deflector as a pre-chopper located at the end of LEBT, operating at the synchrotron initial revolution frequency of 1 MHz. The required beam rise/fall time is approximately several dozens of nanoseconds that is rather tough for the LEBT pre-chopper. Beam testing has been performed to verify the design principle and for better understanding the beam behaviour in the space-charge compensation LEBT.

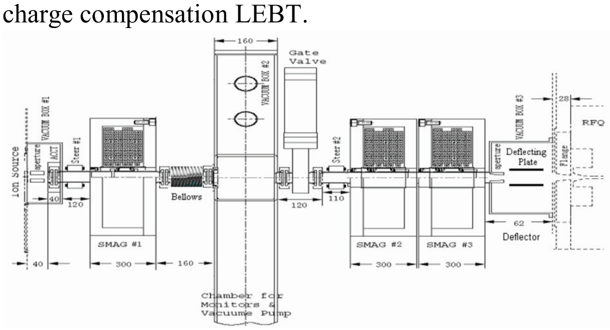

Figure 1: CSNS LEBT Linac layout.

STRUCTURE AND BEAM DYNAMICS

Three possible geometries were investigated; the sloping shape plate is adopted for its simplicity and high average effective deflecting field compared with parallel and semi-cylindrical shape ones. The gap between the deflecting plates is 1.2 times beam size and varies along with the beam envelope. To decrease the capacitance between the two plates, the width of the deflecting plates also varies with the envelope size, which is 1.5 times the envelope size. Meanwhile, a ground potential electrode and an electron-trapping electrode are installed at the upstream deflector in order to confine the destruction of charge neutralization caused by the deflector in the local area.

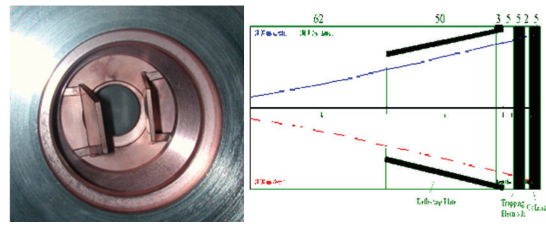

Figure 2: Schematic layout and view of the deflector.

Besides the ion energy and geometry of the electrode, the applied voltage on the deflector mainly depends on the beam-stop distance. The needed voltage turns out to be difficult to achieve in terms of power supply if the entire chopped beam is supposed to be lost on the beam stop located at the front of RFQ. In fact, only if the beam is deflected out of the transverse acceptance ellipse of RFQ in the phase space, then the beam transmission of RFQ is zero and the beam loses completely inside the RFQ cavity. In this way, the deflecting voltage is much lower compared with chopping the beam directly on a beam target or on the flange of RFQ. However, this means that RFQ itself is used as the beam dump of the chopper system, so it must be known how much the total lost beam power is in the RFQ cavity, and what the distribution of the lost beam power is in the RFQ cavity. A multi-particle simulation has been carried out. The lost peak beam power versus the RFQ Cell number is shown in Fig. 3. The most lost beam power is deposited at the beginning of RFQ and the beam is lost in the RFQ cavity basically without acceleration. In practice, although the chopped beam is designed to deposit on the beam target for SNS, there is still much beam lost in the RFQ due to the inadequate deflecting voltage. No damage is found up to now and foreseen in the future [2].

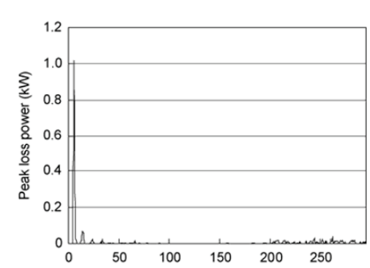

Figure 3: The lost pulse beam power versus the RFQ cell number.

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ELECTRICAL DESIGN

The schematic layout of the chopper circuit is represented in Fig. 4. The key electronic component of the LEBT chopper system is the solid-state switch. A push-pull transistor switch HTS 81-06-GSM is chosen. It is a standard product from BEHLKE power electronics GmbH, Germany. It can provide a rise/fall time of less than 10 ns with 50 pF loaded capacitance. As shown in Fig. 4, a 20 kΩ resistance serves as an over-voltage protective component, which can ensure the security when the switch is turned off and the beam bombards the deflecting plate. The 200 Ω current limiting resistance is essential in almost all the similar circuits. It was replaced by a 100 Ω resistance at the beginning of test in order to further reduce the circuit rise/fall time. The result shows that the circuit rise/fall time decreases from 20 ns to 18 ns, only 2 ns improvement with a doubled peak current, namely 60 A. Consequently, the 200 Ω one was finally chosen for switch security in spite of a peak current capability of 60 A with t_p<10μs and duty cycle <1% for HTS 81-06-GSM.

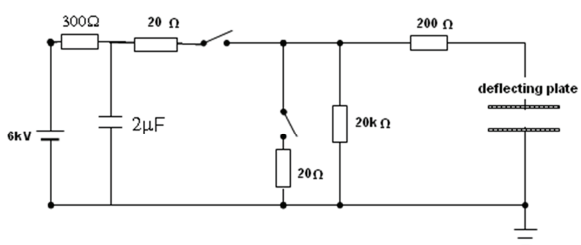

Figure 4: The schematic layout of the chopper circuit.

The power required to charge and to discharge the electrode equivalent capacitance, at the voltage V and repetition frequency f is approximately given by the formula [3]:

$$P = \frac{f \cdot C \cdot V^2}{2} \quad (1)$$

Fast rise/fall time for the chopped beam is required for reducing the beam loss due to the insufficient chopping. The least rise time is determined both by the power supply circuit and by the flight time of the beam particle in the deflecting plates, given by reference [4]

$$\tau_b = t_{r1} + \tau^* \cdot \frac{V^* \tau^*}{\frac{V_m}{t_{r2}} \cdot \frac{1}{2}(t_{r2}^2 - t_{r1}^2) + V_m(\tau^* + t_{r1} - t_{r2})} \quad (2)$$

where V^* is the required deflecting voltage, V_m, the real output voltage, τ^*, un-normalized flight time, t_{r1}, the rise times for the voltage increasing from 0 to V^*, and t_{r2}, the rise times for the voltage increasing from 0 to V_m.

Technical specifications for the power supply are summarized in Table 1.

Table1: Main Parameters for the Chopper Power Supply

Maximum voltage	6kV
Pulsed power (average power)	~300(3)W
Circuit rise/fall time	~10 ns
Loaded capacitance	~10 pF
Micro-pulse width	530 ns
Micro-pulse repetition frequency	0.9433 MHz
Macro-pulse width	40 ms
Macro-pulse repetition frequency	25 Hz

EXPERIMENTS OF THE PRE-CHOPPER SYSTEM

In order to confirm the CSNS pre-chopping design before the construction of CSNS linac, an existing RFQ accelerator at IHEP built in a research program on ADS was used to perform the beam test. A similar chopper system compared with CSNS pre-chopping scheme is established for sake of demonstration. The design is in accordance with the existing LEBT layout and the structure of the vacuum chamber is located at the entrance of the ADS RFQ. A Beam Position Monitor (BPM) is located at the exit of the RFQ to check the beam signal intensity. In chopping experiments, the macro pulse beam width increases from 100 μs to 500 μs and repetition rate increases from 1 Hz to 25 Hz gradually while the 50% chopping rate, the 530 ns chopped pulse beam width and the 32 mA pulsed beam current are kept constant all the time. The beam structure got in the last chopping experiment is basically the one required by CSNS RCS. The chopping results are examined by the BPM as shown in Fig. 5.

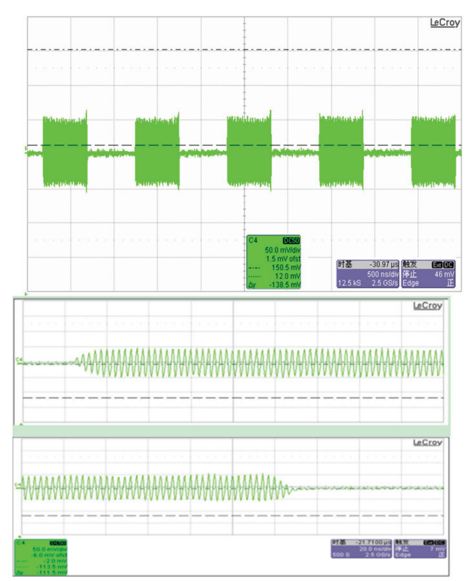

Figure 5: Beam signal of the BPM. Left: 500ns/div right: 20 ns/div.

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In addition, a series of experiments have been also carried out to check the relationship between the RFQ transmission and the deflecting voltage got by PARMTEQM simulations. A good agreement between simulation and test is illustrated in Fig. 6. Although most beam was lost at the beginning of RFQ, no multipacting and spark has been observed in the experiments, and the RFQ still keep working stably during the chopping experiment period. In fact, the special geometry of the RFQ electrode in (Radial Matching Section) RMS is also beneficial to weaken the multipacting compared with the parallel planes.

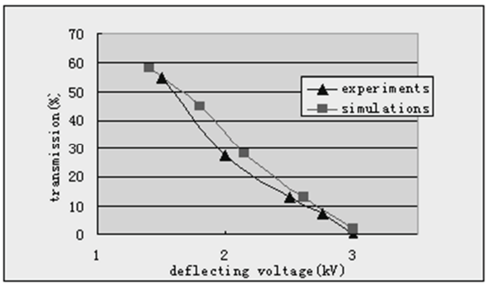

Figure 6: The simulations and experiments results of the deflecting voltage versus RFQ transmission.

As mentioned above, an electron-trapping electrode is used to confine the destruction range to the local area. Calculation shows that the electrostatic potential on the beam axis at the location of collimator is zero when the applied voltage on the electron-trapping electrode is -1.25 kV. In practice, no obvious change was found while the voltage was adjusted from -1.25 kV to -2.5 kV; the measured beam current at the RFQ exit was decreased while the applied voltage on the electrode was lower than -1.25 kV.

The pulse width, the frequency and the voltage fulfil the requirements, and the achieved rise/fall time is less than 20 ns, which is the fastest one compared with other similar pre-choppers. Furthermore, the test shows a good agreement between the experimental results and theoretic results. However, the radiation of the high voltage power supply cannot be negligible, both the LEBT kicker and the beam loss monitor located at the exit of RFQ encountered this radiation.

The electromagnetic interference measurement was performed using Tektronix DPO7254 2.5 GHz oscilloscope. It is confirmed that the electromagnetic radiation comes from the spatial radiation since the interference field strength decreases sharply with a longer distance between the power supply and oscilloscope. In this case, an aluminium rack has been manufactured for shielding the radiation from the input port as shown in Fig. 7. By this way, the interference field strength is reduced by a factor of one third. Moreover, efforts have been made for further decreasing the electromagnetic interference in order to keep the reliability of pre-chopping system and beam instruments.

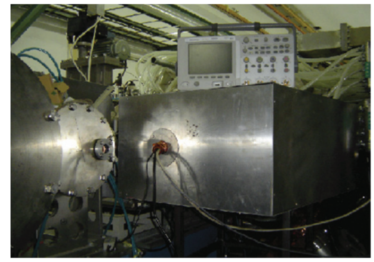

Figure 7: The aluminium rack for electromagnetic shielding.

Fast circuit rise/fall time is one of the most important criteria for a chopper, so a high voltage coaxial cable without shield layer was used as a feed-through. In order to avoid the loop radiation, the single port feed-through was replaced by two port one. In this case, the loop has been insulated, both input and output of power supply has been shielded. The result shows that the electromagnetic strength becomes much lower than before.

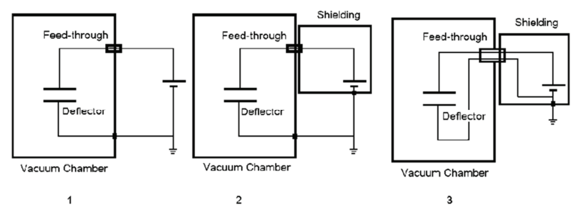

Figure 8: Improvement made for electromagnetic shielding.

CONCLUSION

The design of an electro-static chopper used for CSNS LEBT is described and its main features are discussed. The experiment of a similar pre-chopping system was performed with satisfactory results. The test shows a good agreement between the experimental results and theoretic results. The study has also confirmed that the electro-static pre-chopping system is suitable for CSNS LEBT design. With less than 20 ns pre-chopped beam rise/fall time reached by electrostatic deflector, it turns out unnecessary to use the MEBT chopper for further shortening the rise/fall time.

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