NEW DESIGN OF THE SNS MEBT CHOPPER DEFLECTOR

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Abstract

The chopper system for the Spallation Neutron Source (SNS) provides a gap in the beam for clean extraction from the accumulator ring. It consists of a pre-chopper in the low energy beam transport and a faster chopper in the medium energy beam transport (MEBT). The original “meander line” design of the MEBT chopper deflector was successfully tested with low power beam during the SNS linac commissioning but turned out to be unsuitable for high power beam operation due to poor cooling of the copper strip line through the dielectric substrate. We developed a new deflecting structure, with higher deflection efficiency and with rise and fall time easily customizable to match the available high voltage pulse generator. In this paper we describe design, implementation and beam tests results of the new MEBT chopper deflector.

INTRODUCTION

One of the SNS Front End functions is to provide beam pulse time structure suitable for low loss single turn extraction from the accumulator ring. The 1-ms long H^- macro-pulses has to be chopped at the revolution frequency of the accumulator ring into mini-pulses of 645 ns duration with 300 ns gaps. Beam chopping is performed by two separate chopper systems located in the LEBT and MEBT. The LEBT chopper removes most of the beam charge during the mini-pulse gaps, and the traveling-wave MEBT chopper further cleans the gap to a level of 10^{-4} and reduces the rise and fall time of the mini-pulse to 10 ns. The MEBT chopper system consists of a fast transmission line deflector, a high voltage solid state pulse generator and a target. The main parameters of the original deflector are given in Table 1.

Printed circuit board technology was used to form a slow-wave transmission line on a dielectric substrate. The details of the design can be found in [1]. The chopper systems demonstrated design parameters during the initial commissioning at low average beam power [2]. When the average beam power increased the MEBT chopper deflector failed beyond reparability. Upon disassembly we saw damage apparently caused by overheating of the copper traces. The damage was concentrated along the beam path. We concluded that uncontrolled beam loss was the main source of the heat. The spare deflecting structure failed in the similar fashion. We needed an immediate replacement to support accelerator operations. The original design required quite elaborate manufacturing process therefore the exact replica could not be obtained within a reasonable time frame.

We were facing the problem of finding a design which could be produced within 1-2 months time frame using local manufacturing facilities. It had to satisfy immediate needs of beam operation and be upgradeable to meet the requirements of the nominal beam power.

Table 1. Main parameters of the original MEBT deflector.

Deflector type		Meander TEM line
Ion energy		2.5 MeV
β = v/c		.073
Max Voltage		± 2.5 kV
gap		18 mm
Effective length		~370 mm
Max deflection		1.07 o
Time of flight		~ 17 ns
Power supply rise time		10 ns
Structure rise time		~1 ns

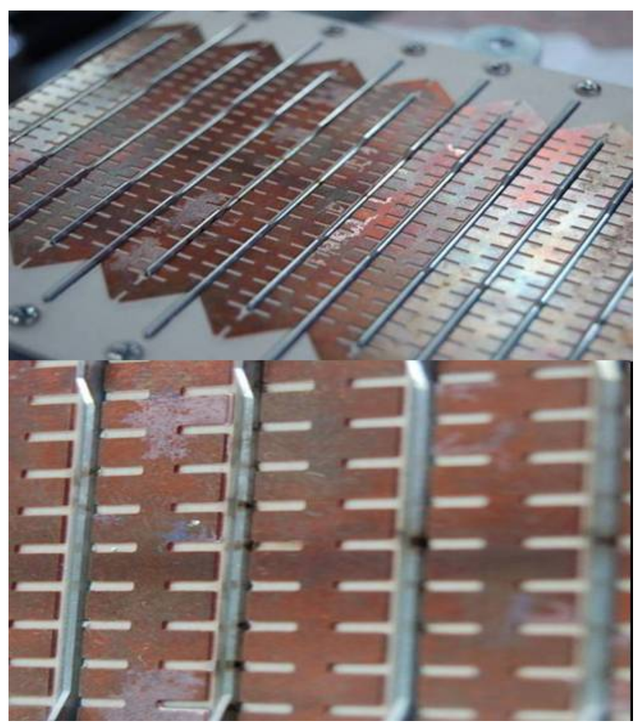

Figure 1. Photo of the damaged PCB structure of the original chopper deflector.

GENERAL DESIGN CONSIDERATIONS

A large number of transmission line deflectors have been developed for medium energy chopper applications over several years; a good review is given in [6]. Implementation details aside, almost all of those designs fall in a few general configurations which we discuss below.

The parameters of interest are deflection rise/fall time and kick strength.

Deflected beam rise/fall time

The rise time of the field in the deflector depends on the high voltage power supply rise time and the deflecting structure bandwidth. The actual rise and fall time of a beam deflected in a traveling wave deflector of length L is

$$\tau = \tau_f \cdot (1 \pm \frac{\beta_p}{\beta_w}); \quad \tau_f = \frac{L}{\beta_p c}, \qquad (1)$$

where β_p is the beam particle velocity , β_w is the effective wave velocity; where the positive sign corresponds to opposite directions of beam and wave propagation, negative sign in the same direction.

Deflecting efficiency

The deflecting efficiency of a transmission line, defined as the ratio of kick strength to the kick strength of an electrostatic plate of the same length at the same voltage is

$$\eta = g \cdot (1 \pm \sqrt{\mu_{eff}\varepsilon_{eff}}\beta_p \cos\alpha) \quad , \qquad (2)$$

where g is the so called coverage factor, α is the angle between beam direction and electrical current in the line, ε_{eff} , μ_{eff} are effective relative dielectric constant and magnetic permeability of the material in the line respectively; where the positive sign corresponds to opposite directions of beam and wave propagation, negative sign in the same direction.

It should be noted that the contribution of the magnetic field (the second term in (2)) is usually small for low β_p beams and often neglected. However, in the material loaded lines effect of the magnetic field is enhanced according to (2) and can affect the deflecting efficiency significantly.

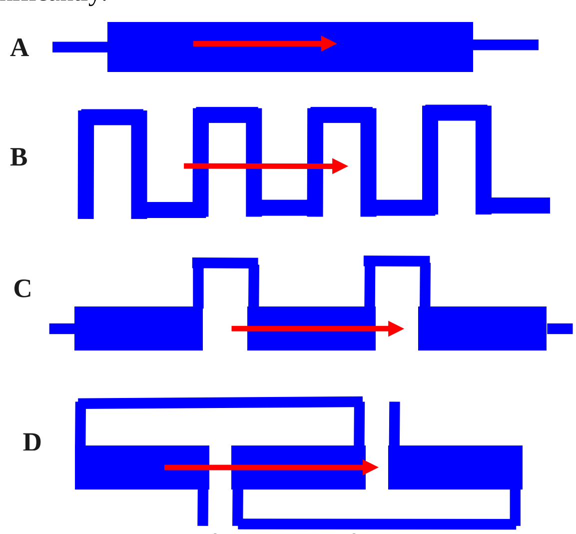

Figure 2. Typical configurations of the transmission line deflectors. See explanation in the text.

Typical configurations

1. Strip line deflector schematically shown in Fig. 2A. The deflection rise time is close to time of flight of particles through the deflector. Deflection efficiency is larger for opposite directions of beam and wave propagation. This structure can provide the highest deflection efficiency.

2. "Meander" line deflector (schematically shown in Fig. 2B) or similar structures where the wave travels over a longer path than the beam therefore the effective wave velocity is reduced and can be made equal to the beam velocity. The deflection rise time then reduces significantly in case of co-propagating beam and wave according to (1). The deflection efficiency is unavoidably reduced by the coverage factor g<1; the contribution from the magnetic field is small because it is parallel to the particle velocity ($\alpha \approx 90^\circ$). This type of structure is preferable for achieving the fastest deflection rise time. Example of such a structure is the original SNS MEBT deflector.

3. Several short strip lines connected by delay lines as shown schematically in Fig. 2C. The length of the delay lines is set to $\Delta T = \frac{L}{c}(\frac{1}{\beta_p} - \frac{1}{\beta_w})$ so that the wave arrives to the beginning of the next line synchronously with the beam. In this case, the deflection rise time is defined by the single strip line length and can be chosen to satisfy the requirements. The deflection strength is the sum of deflection strengths of the individual pieces. The magnetic field contribution reduces the efficiency. Example of such a structure is given in [3]

4. We propose a "Greek key" configuration (schematically shown in Fig. 2D) similar to above in deflection rise time but with the magnetic field contribution increasing the efficiency due to opposite directions of propagation of beam and wave. The length of the delay lines is set to $\Delta T = \frac{L}{c}(\frac{1}{\beta_p} - \frac{2}{\beta_w})$ so that the wave arrives to the beginning of the next line synchronously with the beam. This configuration can provide the best combination of high efficiency and the deflection rise time customizable to the requirements by proper choosing the length of the elementary cell. The efficiency enhancement is more significant for higher energy beam and for dielectric loaded lines.

In the case of the SNS MEBT chopper the total deflection rise time is currently limited by the power supply rise time of ~10ns. Therefore choosing the deflector rise time of less than 5-6ns, which corresponds to ~10cm length of the elementary cell, will result in the total rise time increase of ~10% compared to an ideal case of zero rise time structure. Efficiency enhancement of ~10-15%, though look small, allows a reduction in the power supply voltage from 2.5Kv to ~2.2kV, which is significant factor in improving its reliability.

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NEW MEBT CHOPPER PROTOTYPE

We considered different technologies for building the new deflecting structure. The printed circuit board on ceramic substrate [3,4] looks promising and provides some gain in efficiency due to magnetic field enhancement by high dielectric constant material. However it is fairly complicated [3] and such a structure could not be built in house in a short period of time. In addition, we do not know of any beam tests of a ceramic structure in close proximity to the beam. Therefore we took the most reliable approach of building conventional solid copper strip line supported by off-the-shelf ceramic stand offs as shown in Fig.3,4. The only areas required special attention were minimizing effect of stand-offs on wave propagation and matching a relatively wide copper line to the input feeder. The resulting structure is well matched as illustrated by impulse response shown in Fig.5. In order to shorten the delivery time we utilized many parts from the original chopper including support and alignment elements, and high voltage feedthroughs. For that reason it was convenient to build a single strip line prototype. The expected deflection rise time is 17ns, which is longer than the original design but still represents significant improvement compared to the current conditions [5] and should be sufficient to satisfy beam ramp up needs for at least the next year. The next version will incorporate experience from the beam test of the prototype and its deflection rise time requirements will be formulated based on actual loss minimization needs rather than on model prediction.

We also would like to investigate the PCB technology path further with the main goal of achieving as high deflecting efficiency as possible by proper selection of the substrate material.

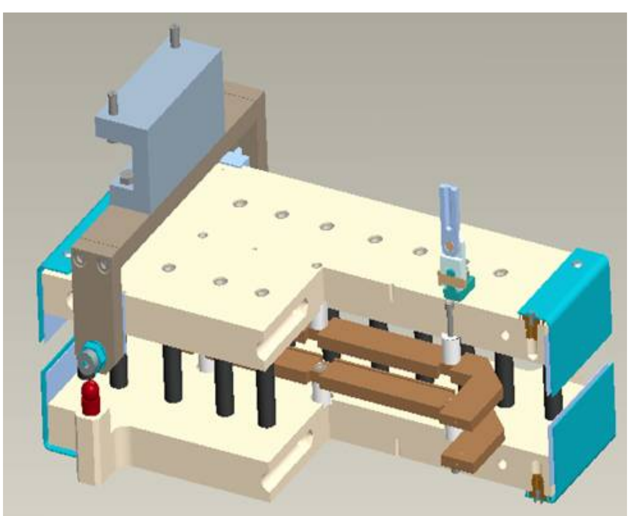

Figure 3. Layout of the new MEBT chopper deflector.

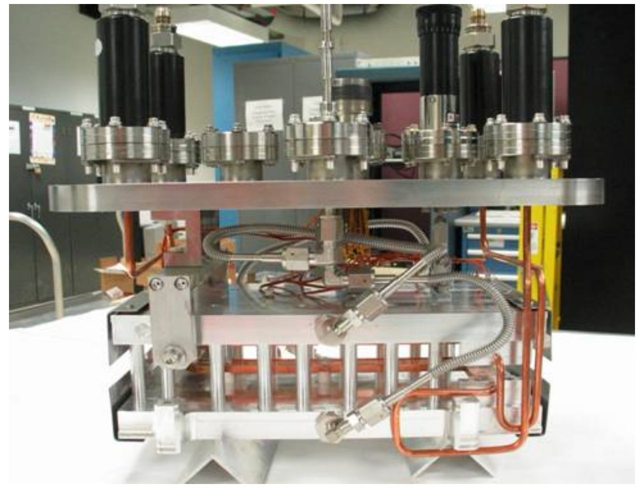

Figure 4. The new MEBT chopper deflector ready for installation.

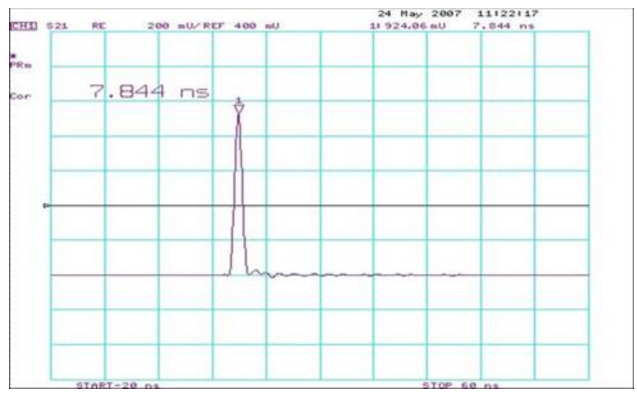

Figure 5. Results of the cold testing. Low voltage short pulse transmitted through the structure.

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