CERAMIC-SUPPORTED TRAVELING-WAVE STRUCTURES FOR SNS FAST BEAM CHOPPER*

Sergey S. Kurennoy#, LANL, Los Alamos, NM 87545, U.S.A.

Abstract

The current structure for the fast 2.5-MeV beam chopper for the Spallation Neutron Source (SNS) project was originally developed [1] to provide rise and fall times around 1 ns. The structure is based on the meander-folded notched strip line with low-dielectric-constant supports and metal separators. Since then the requirements of the chopper rise-time has been significantly relaxed, up to 10 ns, as a result of beam dynamics simulations and to simplify the voltage pulse generators. In addition, initial runs with the beam showed that this structure was prone to damage when accidental beam spills occurred. We suggest alternative meander structures for the SNS chopper that employ high-dielectric-constant substrate (e.g., alumina). Time-domain simulations show their electromagnetic performance to be well within the requirements, while their resistance to beam spills and thermal properties are expected to be much better and fabrication significantly simpler.

INTRODUCTION

In pulsed spallation neutron sources based on full-energy linacs and storage rings, fast beam choppers provide the required time structure of the H^- current within linac beam macro-pulses that creates an extraction gap in the storage ring filling. The chopper rise-fall time requirements depend on the linac bunch spacing; they can be as short as 1 ns. Such fast rise-fall times can be achieved with traveling-wave choppers, like the one developed for the SNS project, see [1, 2]. The traveling-wave MEBT chopper at 2.5 MeV fills the space between its two mirror-symmetric current structures – one carrying a positive and one a negative voltage pulse – with a wave of the deflecting electric field propagating along the beam path at the same speed as the beam does, $\beta=v/c=0.073$ in the SNS case. The chopper current structure is formed by a meander-folded notched 50-Ω strip line on T-shaped low-dielectric-constant supports, with grounded metal separators, see Fig. 1. The notches, separators, and carved ε=2.94 dielectric all serve to reduce the coupling between the adjacent strips while keeping the dispersion small, thus reducing rise-fall times. The structure calculated rise-fall time of 1 ns was confirmed by measurements [1]. Unfortunately, the SNS experience with the beam showed that this fast current structure can be damaged by beam spills or by water that accidentally filled the chopper.

The CERN SPL traveling-wave chopper uses another design for the current structure [3]: a double meander on a solid high-dielectric (alumina, ε=9.7) support, see Fig. 2. The two parallel 100-Ω meanders form a 50-Ω line.

If a beam is traveling at velocity βc along the x-axis, and its deflection is in the z-direction (transverse to the structure plates), the deflecting Lorentz force per unit charge is $F_z / q = E_z + \beta Z_0 H_y$, where $Z_0 = \sqrt{\mu_0 / \varepsilon_0} = 120\pi$ Ω. The maximal deflecting electric field is $E_{max} = V/h$, where $\pm V$ are potentials on two plates and $2h$ is the distance between them. Normalizing the above deflection force to E_{max}, we define the chopper deflection efficiency $\eta = \eta_e - \eta_m$, where $\eta_e = E_z/E_{max}$ is the electric efficiency and $\eta_m = -\beta Z_0 H_y/E_{max}$ is the magnetic reduction.

In the SPL chopper, the tapered connections of the meanders along the beam path (center) are made wide to increase the electric efficiency η_e. However, these connections, where the current flows along the beam direction, also create a noticeable lateral magnetic field. Its contribution to the Lorentz force reduces the electric deflection by about 4.8% in this structure.

The SPL chopper structure rise-fall time is around 2 ns. The structure appears to be more robust than the SNS one due to its use of alumina instead of PTFE for the meander supports.

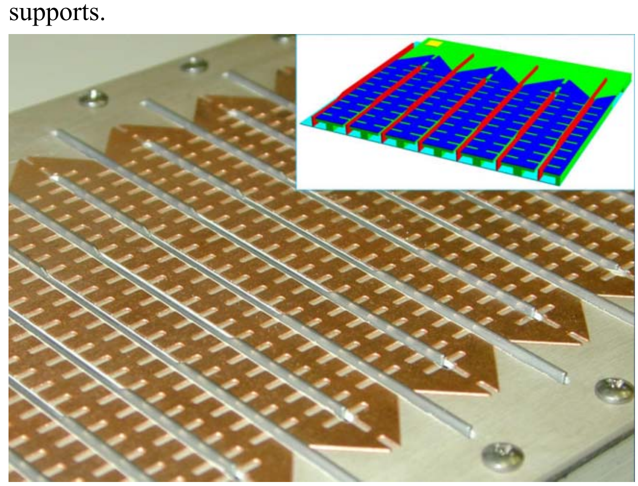

Figure 1: The current structure of the SNS MEBT chopper. The inset (MAFIA model) shows the T-shaped dielectric supports (green) and metal separators (red).

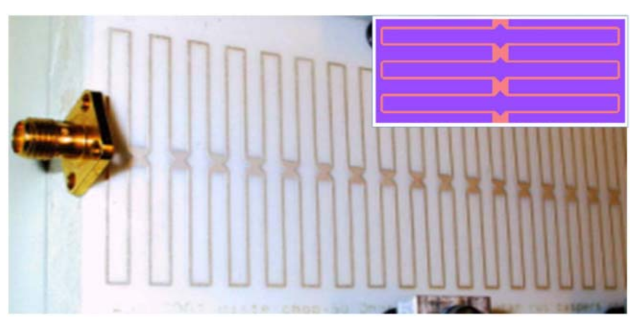

Figure 2: The current structure of the CERN SPL chopper.

*This work was supported by the US Department of Energy under Contract Number DE-AC52-06NA25396

#kurennoy@lanl.gov

1-4244-0917-9/07/$25.00 ©2007 IEEE

Relevant geometrical and electromagnetic parameters of the chopper structures are listed and compared in Table 1.

Table 1: Chopper Structure Specifications

Parameter	**SNS**	**CERN**	**AltSNS**
Beam velocity β	0.073	0.08	0.073
Structure length, cm	35	40	35
Meand. width/period, mm	96/20	40.4/6	35/10
Metal line width, mm	8.0	0.45	2.0
Sub./metal thickness, mm	2.5/0.25	3/≈0.05	3/0.25
Half-gap height h, mm	9	10	9
Maximal voltage V, V	±2350	±500†	±2350
Field rise-fall time, ns	≈ 1	≤ 2	≤ 3
E-deflecting efficiency η_e	0.89	0.78	0.86
Magnetic reduction η_m	<0.002	0.037	0.005

† Due to the pulser; the structure itself was tested at 2 kV.

ALTERNATIVE MEANDER STRUCTURE FOR SNS MEBT CHOPPER

We propose very simple meander current structures for the SNS MEBT chopper that use elements of both the designs described above. One possible structure is shown in Fig. 3. The solid alumina substrate (grey, ε=9.7) clamps the electric field around the 50-Ω strip line (yellow) thereby reducing the coupling. The structure parameters are listed in Tab. 1. The transparent box in the bottom picture shows one-half of the chopper volume. The arrows indicate the electric (green) and magnetic (blue) field probes along the beam path. Two red spots show the signal input and output locations.

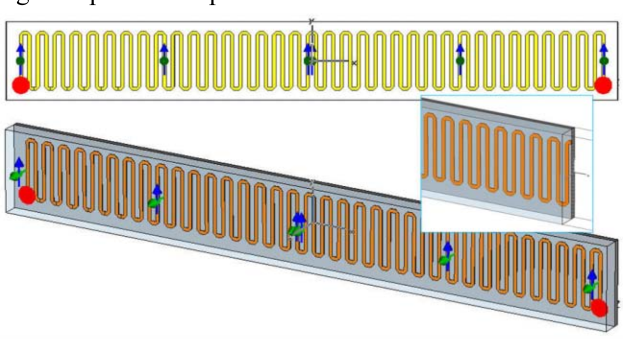

Figure 3: MicroWave Studio model of the full alternative structure for the SNS MEBT chopper. Top – top view.

The meander width is quite small, only 35 mm, so the structure can easily fit inside quads if necessary. The structure performance was studied using EM simulations with the CST MicroWave Studio (MWS) [4].

MWS Modeling Results

The designed meander line is well matched to 50 Ω, as evidenced by the structure S-parameters plotted in Fig. 4. The reflections are small, especially at low frequencies, which are mainly of interest here.

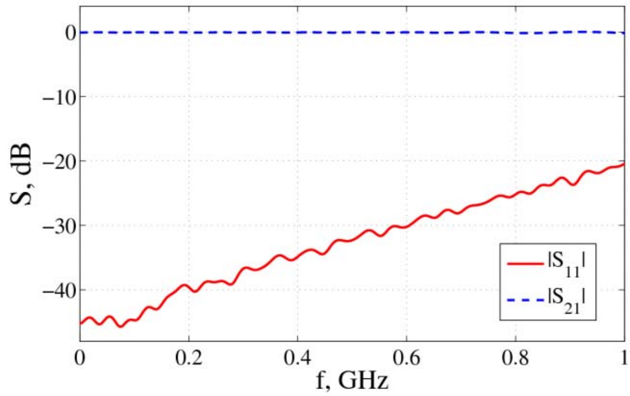

Figure 4: S-parameters of the alternative SNS structure.

Taking into account dielectric losses in alumina, even as large as tan δ = 0.004, does not lead to any noticeable changes in the S-parameter plot. MWS simulations with dielectric losses take about twice as long as without them.

Figure 5 shows the fields created by a voltage pulse with a 3-ns sin^2 rise and fall and 7-ns flat top, in three different points along the beam path – ¼, ½, and ¾ of the structure length. The electric field recorded by two probes near the structure ends is 25% lower than in Fig. 5 due to edge effects; the magnetic field is about 30% higher since there is no compensation from adjacent strips. The fields in Fig. 5 are normalized to the maximal electric field E_{max}, so that the curve values at the pulse flat-tops in the plots give directly the electric deflecting efficiency η_e (top) and magnetic reduction η_m (bottom). The magnetic reduction of the beam deflection here is less than 0.6% of the electric kick, about eight times smaller than in the CERN SPL double meander.

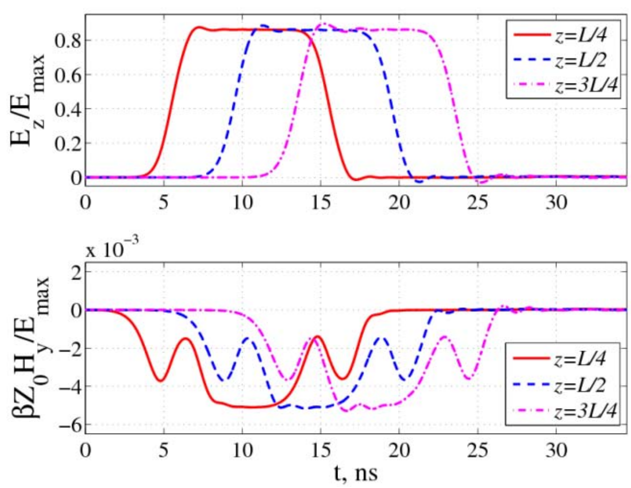

Figure 5: Fields in the alternative SNS structure for the sin^2 3-7-3-ns voltage pulse.

One can observe small overshoots in the electric field that develop due to dispersion as the pulse propagates along the structure. The largest ripple reached in the output signal is slightly below 7% of the flat-top value. The magnetic field shows oscillations during the pulse

1-4244-0917-9/07/$25.00 ©2007 IEEE

fronts and ends, in between its value remains constant. For a similar pulse with the shorter front and end, 1 ns instead of 3 ns, and the same 7-ns flat top, these magnetic-field oscillations become 2-3 times larger in amplitude, while the flat-top remains the same, apart from some ripples. The changes in the electric field are less dramatic; some ripples develop on the flat tops, especially by the structure end. The largest overshoot of the output signal reaches about 25% of the signal flat-top magnitude.

Figure 6 presents the deflecting field snapshots in the beam plane for the pulse in Fig. 5 taken at t = 14.5 ns. The voltage amplitude on the pulse flat-top is about 7 V.

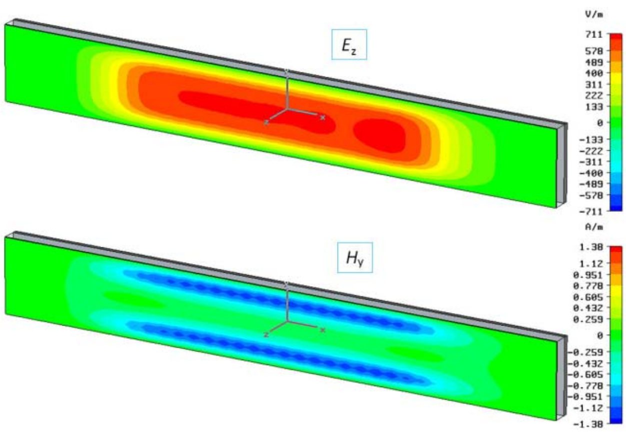

Figure 6: Field snapshots in the beam plane for the same $\sin^2$ 3-7-3-ns voltage pulse as in Fig. 5, taken at t=14.5 ns.

The other field components are not shown in Fig. 6; they are much smaller. One can see that the deflecting electric field is rather uniform. The magnetic field is mainly concentrated near the meander edges while along the beam path its magnitude is quite small.

From a numerical viewpoint, the MWS simulations of this chopper structure are straightforward and relatively fast. With a detailed mesh of about 1.1 million mesh points, a typical time-domain run to get results similar to those in Figs. 4-6 takes about 1-1.5 hours on a PC with dual 3.2-GHz Pentium Xeon processors.

Structure Fabrication Technology

The SNS chopper manufacturing process was relatively complicated, see in [5]. The T-shaped support that goes all along the strip line was carved from a continuous dielectric plate of duroid RT/6002, after the notched meander pattern was chemically etched on the copper coating of the dielectric. The dielectric plates with the required copper coating were commercially available from Rogers Corp. The whole structure was clamped by bolts near its sides to the machined metal ground plate with separators, and the dielectric supports were glued to the ground plate with a special epoxy to provide the required line flatness. The ground plates were fabricated of 6061-T6 aluminum alloy. The water cooling channels were drilled through the ground plates.

In the case of alumina substrate, metal has to be deposited on the dielectric. For creating copper coating on alumina one can employ, for example, the Plated Copper on Thick Films (PCTF©) technology by REMTEC [6]. It provides the copper-line thickness up to 0.010″ (0.25 mm) to handle high currents, up to tens of Amperes – exactly what is required for this application.

Another technology was developed by Kyocera for the CERN SPL chopper, see in [7]. It can also be used in this case but probably better suited for thinner strip lines.

CONCLUSION

A new current structure for the SNS MEBT fast beam chopper is proposed. It employs a simple meander line on a high-dielectric-constant (alumina) substrate. The width of the meander is narrow, so it can fit inside magnetic quadrupoles if required. Time-domain simulations with the MicroWave Studio showed that the electromagnetic performance of the structure is very well within the existing requirements, with the rise and fall times below 3 ns. The structure resistance to beam spills and its thermal properties are expected to be much better than for the existing structure, due to radiation resistance and good thermal conductivity of alumina. On the other hand, the structure fabrication appears to be significantly simpler compared to the existing one.

One should mention that a 100-Ω single-meander structure with alumina substrate was considered for the CERN SPL chopper in [3]. The line parameters were close to those in Tab. 1 (column CERN), with the meander width around 20 mm. The structure electric efficiency was estimated to be 0.74. However, the magnetic effects were not taken into account. Since the meander width was almost the same as the chopper gap, one can expect them to be noticeable in that case, due to a relatively large lateral magnetic field near the beam axis.

The author would like to acknowledge useful discussions with A. Aleksandrov and C. Deibele of SNS, and F. Caspers of CERN.

REFERENCES

[1] S.S. Kurennoy and J.F. Power, “Development of Meander-line Current Structure for SNS Fast 2.5-MeV Beam Chopper,” EPAC 2000, Vienna, p. 336.
[2] S.S. Kurennoy, J.F. Power, D.L. Schrage, “Meander-line Current Structure for SNS Fast Beam Chopper,” PAC 1999, Chicago, p. 1399.
[3] F. Caspers, A. Mostacci, S. Kurennoy, “Fast Chopper Structure for the CERN Superconducting Proton Linac,” EPAC 2002, Paris, p. 873.
[4] MicroWave Studio, v. 2006B. Computer Simulation Technology (CST), www.cst.com.
[5] S.S. Kurennoy et al. “Progress with SNS Fast Beam Chopper,” PAC 2001, Chicago, p. 1435.
[6] REMTEC. www.remtec.com.
[7] T. Kroyer, F. Caspers, and E. Mahner. “The CERN SPL Chopper Structure: A Status Report,” CERN CARE-Report-06-033-HIPPI (2006).

1-4244-0917-9/07/$25.00 ©2007 IEEE