FUNNEL CAVITIES FOR 4-MW UPGRADE OF SPALLATION NEUTRON SOURCE*

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Abstract

The Spallation Neutron Source (SNS) project [1] includes a future upgrade option to 4 MW of beam power. The upgrade scenario stipulates adding a second front end and drift-tube linac, and then merging two 402.5-MHz beams from the parallel legs by interlacing them into a single 805-MHz beam at the entrance to the main linac. The funnel energy is chosen to be 20 MeV. The beam funnel section requires two types of rather special cavities: the two-beam buncher and the RF-deflector. The design options of the funnel cavities and some results of their 3-D electromagnetic modeling with MAFIA are presented. These results show feasibility of the beam funneling for the SNS upgrade.

1 BEAM FUNNELING

The beam funneling combines two beams with frequency *f* and current *I* into a single beam of current *2I* at frequency *2f*, see [2] for references. For the SNS 4-MW upgrade the funneling will provide the 110-mA H^--current in the 1-GeV 805-MHz linac by merging two 402.5-MHz beams at 20 MeV [1]. The main reason for the funneling is that the output current of existing H^--sources is limited. While increasing the effective current, the funneling keeps the charge per bunch the same. The concept of the beam funneling by the longitudinal interlacing of two beams is illustrated in Fig. 1. In the SNS case, two 56-mA beams are delivered by two separate front-end sections (each one includes an ion source, RFQ and DTL) that are phased 180° apart.

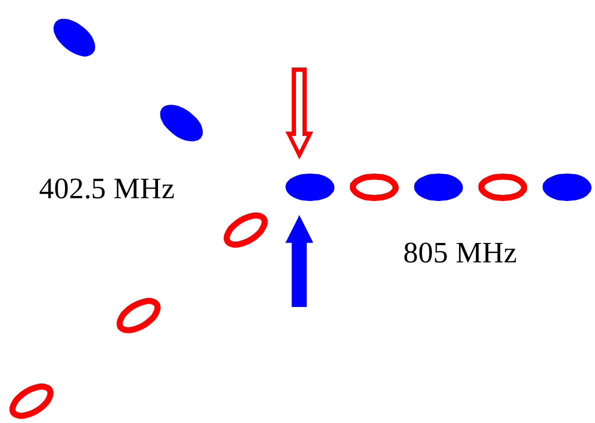

Figure 1: Scheme of beam funnel in SNS. The arrows illustrate the action of an RF deflector.

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In addition to two regular beam lines with bending magnets and focusing elements, the SNS funnel section design [1] requires two special cavities. The two-beam buncher provides the longitudinal focusing of the beams when they are close to each other, just before the RF deflector. The RF deflector alternatively kicks the merging beams in the transverse direction to stir them onto a common axis in a matching section

2 TWO-BEAM BUNCHER

The two-beam (or two-channel) buncher cavity contains two DTL-type two-gap segments. Two beam channels are on both side of the cavity axis and have a 1.68° tilt with respect to it. Since the cavity geometry is essentially 3-D, we apply the MAFIA code package [3] to analyze it. A MAFIA model for one-quarter cut of the two-beam buncher cavity is shown in Fig. 2. Symmetry with respect to the two cut planes is assumed. The drift-tubes (DTs, red) of both channels slightly overlap. The central DTs are supported by stems (dark-blue), which also provide water-cooling paths to DTs.

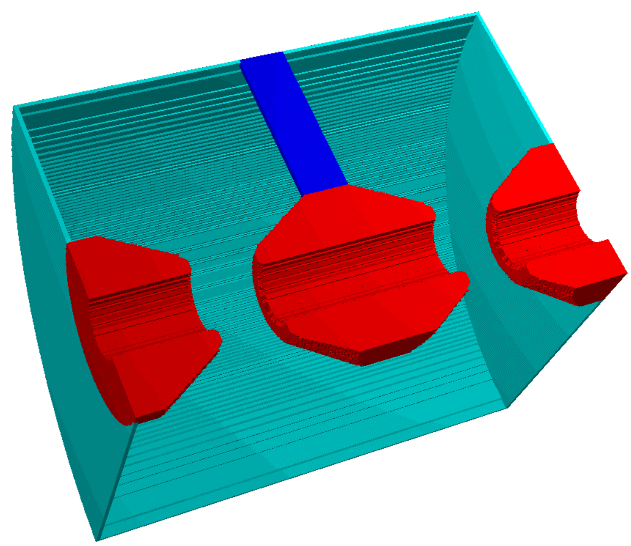

Figure 2: Two-beam buncher cavity (one quarter).

The cavity design frequency is 805 MHz. Its length is chosen to be $2\beta\lambda$=15.14 cm, where β=0.203 for 20 MeV H^--ions, and λ=37.24 cm for 805 MHz. The spacing between the gap centers is $\beta\lambda$ and the gap length is $\beta\lambda/4$. The beam entrance centers are 4.9 cm apart, while the exits are separated by 4 cm. Based on previous experience [4], we choose to model untilted DTs to avoid errors introduced by discretization of slightly tilted shapes.

The electric field pattern of the operating 805-MHz mode is shown in Fig. 3. For the preliminary design the mode frequency was adjusted by changing the cavity radius (sensitivity is about -8.5 MHz/mm); the final tuning will be provided by tuning plugs. This mode is well separated from the lower, stem mode (around 500 MHz) and higher modes (>1.3 GHz).

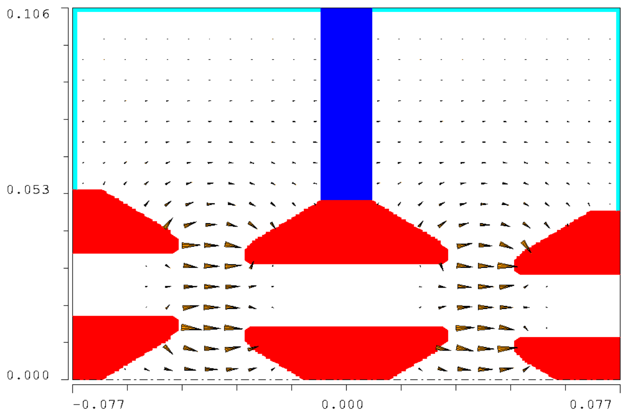

Figure 3: Electric field in the upper half of the buncher cavity cross section. All dimensions are in meters.

Some parameters of the fundamental mode are listed in Table 1. We assume here that the total voltage on the cavity is equal to 625 kV.

Table 1: Buncher 805-MHz Mode Parameters

Parameter	Value
Average longitudinal E field	4.1 MV/m
Maximum E field	29.9 MV/m (1.15 Kp)
Maximum B field	0.033 T
Total stored energy	0.222 J
Total dissipated power*	50.8 kW
Max power loss density*	233 W/cm^2
Q-factor	22725

*CW; for SNS, should be multiplied by the duty factor, about 0.07.

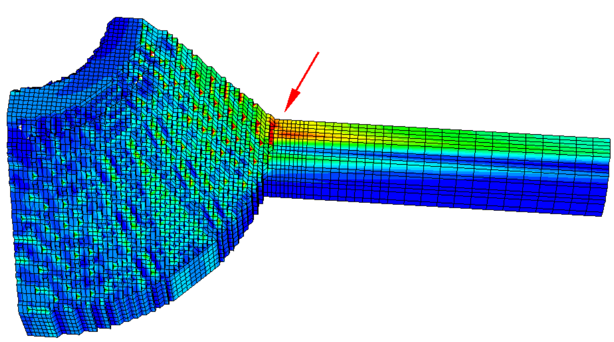

Figure 4: Surface power loss density near the stem-DT connection: the highest density is indicated by red (also by arrow), and the lowest one by dark-blue.

The maximal magnetic field and, correspondingly, the highest surface loss density are near the connection of the stem and DT. The calculated power loss density in this region is shown in Fig. 4, where the red area corresponds to the loss density above 200 W/cm^2 (CW). Making the stem thicker can further reduce the power density.

3 RF DEFLECTOR

The RF deflector provides an alternating 1.28° deflection for two 20-MeV beams entering it, as shown in Fig. 1. The working mode frequency has to be 402.5 MHz, and its transverse electric field between the tips of the cavity deflecting element acts alternatively on one of the two beams. The layout of the RF deflector cavity is illustrated by a 3-D MAFIA model in Fig. 5; it is based on the previous study performed for the ADTT program [5]. The beam path in Fig. 5 is along the upper front edge of the drawn box, and the deflecting element is shown in red.

The total cavity length is about 22 cm, while the distance between the centers of two gaps separating the deflecting element and beam ports is equal to $\beta\lambda/2$=7.57 cm. The gap width between the tips of the deflector is 16 mm, as well as the radii of the beam pipes.

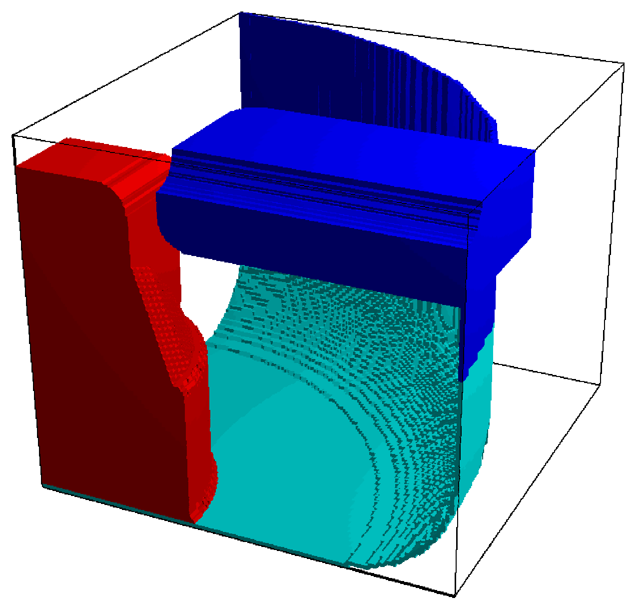

Figure 5: RF deflector cavity (one eighth is shown).

The calculated electric field of the deflecting mode is shown in Fig. 6: the electric field is mostly concentrated in the deflector gap. The magnetic field of the mode is rather low in the gap; it mostly fills the cavity, with the maximum near the side surfaces of the deflecting element. Obviously, the highest surface loss density is also on the sides of the deflector. However, its cooling should not present a problem since the deflecting element is thick enough to allow multiple cooling channels.

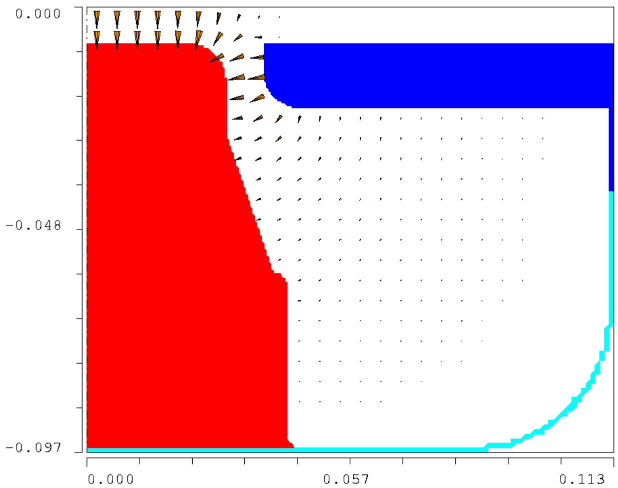

Figure 6: Electric field of the deflecting mode in the right lower quarter of the cavity cross section. The beam path is along the upper side of the drawn box.

A simple way to tune the operating mode frequency in the design is by changing the radius of the deflecting element base, where the magnetic field is rather large. The parameters of the working mode of the RF deflector are collected in Table 2. The cavity voltage is chosen to provide the required deflection of 1.28°.

Table 2: Parameters of Deflecting Mode

Parameter	Value
Deflecting E field: maximum average in the gap	19.7 MV/m 11.6 MV/m
Maximum E field	33.2 MV/m (1.7 Kp)
Maximum B field	0.025 T
Total stored energy	0.213 J
Total dissipated power*	44.5 kW
Max power loss density*	146 W/cm^2
Voltage across the gap	316 kV
Q-factor	12105

*CW; for SNS, should be multiplied by the duty factor, about 0.07.

The cavity parameters are not difficult to achieve. We have also looked at a possibility of an RF deflector cavity, which includes, in addition to the main deflecting mode, also the third harmonic of the deflecting field, at 1207.5 MHz. The cavity design is similar to that shown in Fig. 4. The third harmonic tuning to the required frequency is done by adding a wide circular bulge at the half-height of the deflecting element, see Fig. 7. The tuner's influence on the frequency of the first harmonic is relatively weak. If required, using the third harmonic can further relax the cavity operational parameters; however, the price of that is a more complicated RF system, with two separate RF sources.

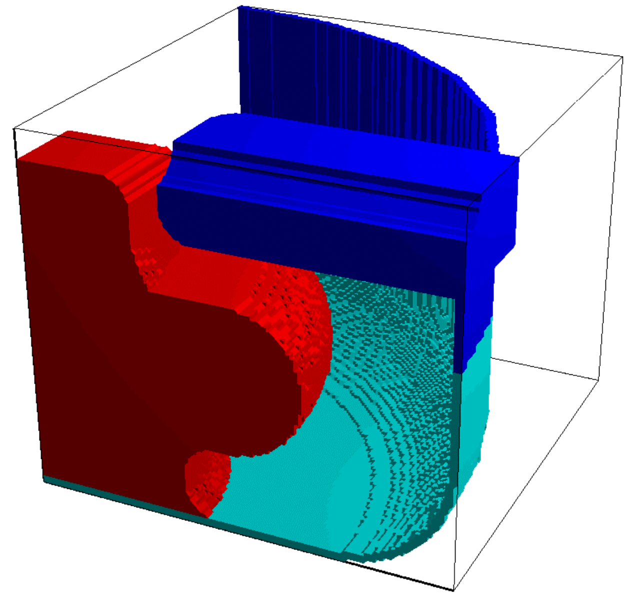

Figure 7: RF deflector cavity with the 3rd harmonic tuned (one eighth).

4 SUMMARY

The preliminary results reported above show that the special cavities for the two-beam funnel in the SNS are feasible. The cavity dimensions will be used in beam dynamics simulations to optimize the funnel section design.

The calculated dissipated power and the density of power loss quoted in Tables 1 and 2 are CW values. They are rather high and would be extremely difficult to achieve for the CW operation. However, the SNS is a pulsed machine. The corresponding power losses in the SNS funnel cavities, obtained by multiplying the CW values in Tables 1 and 2 by the duty factor 0.07, are quite reasonable.

The authors would like to acknowledge useful discussion with James Billen and George Neuschaefer.

5 REFERENCES

[1] NSNS Collaboration, "NSNS Conceptual Design Report", NSNS-CDR-2/V1, Oak Ridge, TN (1997); also available at URL: http://www.ornl.gov/~nsns/nsns.html

[2] T.P. Wangler, "Principles of RF Linear Accelerators" (John Wiley & Sons, NY, 1998). – p.362.

[3] "MAFIA release 4.00" (CST, Darmstadt, 1997).

[4] F.L. Krawczyk et al., in Proceed. ADTT Conf., Las Vegas, NV, 1994; Report LA-UR 94-2733, Los Alamos (1994).

[5] F.L. Krawczyk, in Proceed. PAC95, Dallas, TX, 1995; Report LA-UR 95-1450, Los Alamos (1995).