TITLE: SNS LINAC: REVISED CONFIGURATION

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SNS Linac: Revised Configuration

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The SNS Linac is required to provide a pulsed 1-GeV 1-mA-average beam of H^+ ions to a storage/compressor ring which then delivers it to a neutron production target with high reliability and availability. Nominal rep rate is 60 Hz with a linac pulse length of 1 ms. The entire Linac is required to support a 2-mA operation; thus a facility upgrade to 2 MW merely requires doubling the injected beam current and providing the additional needed rf power. (The design basis for the Linac upgrade to a 4-MW level is a 20-MeV beam funnel.) In order to permit hands-on maintenance, the beam losses in the Linac must be less than 1 nA/m at 1 GeV.

To meet the goals of the project, briefly noted above, an appropriate Linac configuration was chosen as described in the CDR (NSNS/CDR-2/V1, May 1997). The detailed beam-dynamics simulations for this CDR configuration, shown in Figure 1, was described in the document noted above. The first structure is a 402.5-MHz drift tube linac (DTL) which takes the energy to 20 MeV. The final three components of the CDR linac, CCDTL1, CCDTL2, and the CCL, operate at 805 MHz. The frequency jump at 20 MeV permits funneling for the 4-MW upgrade. The lattice period for the 805-MHz portion was $11 \beta\lambda$.

Figure 1. The CDR (May 1997) Linac configuration

Based primarily on value engineering considerations relating to Linac support stands, ease of the placement, alignment, and possible replacements of the quadrupole magnets and diagnostic components, and other constraints such as adequate gaps between the accelerating segments for electromagnetic quadrupoles and diagnostics, we propose a revised Linac configuration. It should be noted that this revised configurations represents only a small change; the basic Linac architecture consisting of the three types of accelerating structures, DTL, CCDTL, and CCL, has not changed. In this brief note we present the overall physics and engineering design considerations and the revised Linac configuration.

Physics Design Considerations

Key design factors are minimization of beam loss and the use of appropriate efficient rf structures throughout the accelerating process. The elements for a low-beam loss design are emittance control and the avoidance of beam halos.

Emittance Control. It is important to control the growth of the rms (and total) beam emittance (the phase space volume occupied by the particles). Design for good emittance control is especially critical in the low-energy portion of the accelerator, where space-charge forces are large. Design features that lead to minimal emittance growth include: (1) the use of high rf frequencies to reduce the charge bunch for a given average beam, (2) strong transverse focusing, and (3) careful matching between adjacent structures.

Avoidance of Beam Halo Formation. Although the causes of beam halo formation are not completely understood, simulations have shown that nonlinear processes within the beam act to eject some particles from the beam core into the halo. These processes are driven by time-dependent collective space-charge forces arising from mismatches of various kinds. Transitions in the phase-space acceptance arising from sudden changes in transverse and longitudinal focusing also appear to drive particles into the halo. The transitions at low energies are especially critical in this regard. The effects due to mismatch (or poor match) at low energies may not be discernible till much later on in the acceleration process. (Hence the importance of end-end simulations). The SNS Linac design aims at minimizing transitions.

Large Ratios of Physical Linac Apertures to the Beam Size. In order to avoid (or to minimize) the beam intercepting the walls of the accelerating structures, the ratio of the physical aperture to the beam size must be kept large. This is especially critical for the high-energy portion of the Linac. Our simulations indicate that for the CCL, the beam bore size must be ~ 10 - 15 times the rms beam size (or ~ 4 - 5 times the total beam size). These estimates are based on our earlier work concerning error and tolerance studies for the 'room temperature' APT design.

Other desirable features to assure low beam loss include: (1) large ratio of longitudinal acceptance to rms longitudinal emittance, (2) tight rf-amplitude and phase control, and (3) precise transverse-beam-position alignment.

Choice of accelerating structures. The Linac accelerates H^- ions from 2.5 MeV to 1 GeV. The appropriate accelerating structures, based on shunt impedance considerations, are the DTL for low- β , the CCDTL for intermediate- β and the CCL for the higher portion of the accelerator. (Please see NSNS/CDR-2/V1, May 1997, for a detailed description.) The design basis for the 4-MW upgrade is the 20-MeV funnel. This choice is based on a detailed study for the room-temperature APT linac design.

Engineering Design Considerations

Since the CDR was completed in May 1997, engineering design layouts for individual Linac components have shown the need to modify the Linac architecture. These issues are discussed below.

Intersegment spacings. Figure 2 shows the intersegment spacings for the 805 MHz components for the CDR Linac configuration. An appropriate quadrupole must be installed in every such gap; additionally, some diagnostic elements must be accommodated, perhaps not in all gaps. Beam-tube connecting flanges are needed to connect the modules, each approximately 1.5 to 2 m in length. Finally, some gaps must have space for gate valves.

Figure 2. Intersegment spacings for the 805 MHz structures of the CDR Linac

Post CDR design work has shown that the intersegment gaps for the entire CCDTL2, the portion accelerating the beam from 68 MeV to 95 MeV, and the low energy part of the CCL, starting at 95 MeV, are inadequate for the components needed.

Location of the major coupling cells. Figure 3 shows the coupling cell clocking for the CCL for two cases: even and odd number of cells per segment. As shown, with even number of cells per segment, all the major coupling cells are located on the same side. This could be an advantage from the point of view of the Linac support stand and for the installation, alignment, and possible replacement of the quadrupole magnets.

Even # of Cells per Segment, C-Cells Same Side

Odd # of Cells per Segment, C-Cells Alternate

Figure 3. Coupling-cell clocking for the two cases: even and odd number of cells per segment. The coupling cells are all on one side for the even case, while they alternate for the odd case.

Orientation of the major coupling cavities. Major coupling cells will have one of two orientations as shown in figure 4: parallel or perpendicular to the beam axis. This orientation is determined by the length of the intersegment gaps in units of $\beta\lambda/2$. Two cases are shown in figure 4.

As shown in the figure the gap, $n\beta\lambda/2$, determines the coupling cell orientation; if n is even then the coupling cell is on-axis. The on-axis orientation of the coupling cell is easily amenable to an upgrade.

Even Spacing - Horizontal Cell

Odd Spacing - Vertical Cell

Figure 4. Coupling cell detail

If the number of cells per segment in the CCL is chosen to be even, and the coupling cell orientation is desired to be on-axis, then the lattice period is constrained to be an even multiple of $\beta\lambda$. This is illustrated by the example shown in Figure 5.

12 $\beta\lambda$ lattice period
8 cells/segment

Figure 5. For a CCL with a 12 $\beta\lambda$ lattice period and 8 (even) cells per segment the intersegment gap is 4 (even) multiple of $\beta\lambda/2$, and hence has on-axis coupling cavities.

Revised Linac configuration

A revised Linac configuration consistent with the above engineering considerations is shown in figure 6.

Figure 6. Revised Linac configuration

As noted earlier, for the CDR Linac, the intersegment gaps for the high energy component of the CCDTL, i.e., CCDTL2, and the low energy portion of the CCL, were deemed inadequate. The revised Linac configuration eliminates the transition at ~68 MeV between the two components of the CCDTL; we now have a single CCDTL all the way from 20 MeV to ~100 MeV. The CCL is now broken up into two components: the low energy section, CCL1, has 8 cells per segment thereby alleviating the intersegment gap problem, and the high energy section, from ~200 MeV to 1 GeV, has 10 cells per segment. The lattice period for both components of CCL is now $12\beta\lambda$. The intersegment gaps for the revised configuration are shown in figure 7.

Figure 7. Intersegment gaps for the three 805 MHz structures for the revised configuration

The minimum intersegment gap is now 19 cm as opposed to 13.4 cm for the CDR Linac. The gaps between the adjacent structures are determined by the matching scheme used. Coupling cavities for all three 805 MHz structures for the revised Linac configuration are on one side. The orientation of the coupling cells for the two CCL structures are on-axis.

In summary, the linac layout which satisfies the requirements and constraints based on value engineering considerations is shown in Figure 6. The linac consists of three types of rf accelerating structures. The first of these structures, the drift tube linac (DTL), operating at 402.5 MHz, accelerates the beam from 2.5 MeV to 20 MeV. The lattice period for the DTL is $4\beta\lambda$ at 402.5 MHz ($8\beta\lambda$ equivalent at 805 MHz). The remaining accelerating structures, the CCDTL and the CCL, operate at 805 MHz. The frequency jump at 20 MeV permits funneling beams from two DTLs for the 4-MW upgrade. The transition energy of 20 MeV between the two structure types, is appropriate for beam funneling. The CCDTL takes the energy to 95 MeV where the transition to the CCL takes place. The lattice period for both the CCDTL and the CCL are $12\beta\lambda$. The bulk of the acceleration, 95 MeV to 1 GeV, takes place in the CCL. The low-energy component of the CCL (95 MeV to 165 MeV), labeled CCL1 in Figure 6, consists of 8 cells/segment. (The term "segment" refers to a contiguous section of accelerating cavities between two quadrupole focusing magnets). The high-energy component of the CCL (165 MeV to 1 GeV), labeled CCL2, consists of 10 cells/segment.

The coupled cavity structures use an even number of cells/segment. Thus, all of the intersegment coupling cavities will be located on one side of the machine, simplifying the mechanical design and reducing the vacuum-manifold complexity. Furthermore, since the intersegment spacings are even multiples of $\beta\lambda/2$, the major coupling cavities are on-axis and are thus easily amenable to reconfiguration for the linac upgrade.

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