MECHANICAL ENGINEERING OF A LINAC FOR THE SPALLATION NEUTRON SOURCE*

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Abstract

The linac for the Spallation Neutron Source (SNS) Project will accelerate an average current of 1 mA of H^- ions from 20 MeV to 1 GeV for injection into an accumulator ring. The linac will be an intense source of H^- ions and as such requires advanced design techniques to meet project technical goals as well as to minimize costs. The DTL, CCDTL and CCL are 466m long and operate at 805 MHz with a maximum H^- input current of 28 mA and 7% RF duty factor. The Drift Tube Linac is a copper-plated steel structure using permanent magnet quadrupoles. The Coupled-Cavity portions are brazed copper structures and use electromagnetic quads. RF losses in the copper are 80 MW peak, with RF power supplied by 52 klystrons. Additionally, the linac is to be upgraded to the 2- and 4-MW beam power levels with no increase in duty factor. We give an overview of the linac mechanical engineering effort and discuss the special challenges and status of the effort.

1 INTRODUCTION

Los Alamos will design, build and install the 1-MW H^- linac for the SNS facility. The mechanical engineering responsibility for the linac includes design, analysis, fabrication, assembly, installation & mechanical checkout. The total cost estimate for the mechanical engineering effort is $130 M. The linac accepts a 2.5-MeV H^- beam from the Front-End System being built by Lawrence Berkeley Lab. The Los Alamos linac system is comprised of three major structure types. A Drift Tube Linac (DTL) accelerates the input beam to 20 MeV, a Coupled Cavity Drift Tube Linac (CCDTL) accelerates the beam to 87 MeV, and a Coupled Cavity Linac (CCL) completes the acceleration to 1 GeV and delivers the beam to the Brookhaven-designed High Energy Beam Transport line that leads to the accumulator ring. The CCL is comprised of an 8-cell per segment section and a 10-cell per segment section with the transition point at 295 MeV. The DTL runs at 402.5 MHz while all the coupled cavity structures run at 805 MHz.

2 DESIGN REQUIREMENTS

Selected requirements and overall design parameters are listed in Table 1. The design activity is being completed using the Unigraphics suite of computer-aided design and manufacturing tools. This includes the UG/MGR and IMAN product data management tools. Other engineering software packages being used include ANSYS, COSMOS/M and CFX.

Table 1. Overall linac requirements	
Input H- Energy	2.5 MeV
Output H- Energy	1001 MeV
Average Beam Current	1.04 mA
Average Beam Power	1.04 MW
Macropulse Repetition Rate	60 Hz
Macropulse Length	0.974 ms
Beam Duty Factor	5.84%

Overall, the design of the SNS linac is similar to the LANSCE linac. The primary difference is that the accelerating gradient is twice as high, allowing a much shorter linac with higher RF power. The design must be capable of being upgraded to the 2 MW level by doubling the current and the 4 MW level by funneling at 20 MeV. To prepare the structure for these upgrades, each accelerating module (driven by two 2.5 MW klystrons for the 1 MW linac output level) is designed with a terminated drive port to accept a third klystron.

Table 2 Linac Design Parameters	
Average Accelerating Gradient, E0T	2.7 MV/m
Avg Energy Gain/Real Estate Meter	2.02 MeV/m
Peak Structure Power Losses	80.2 MW
Peak RF Power	97.8 MW
RF Duty Factor	7.02%
Average RF Power to Linac	6.8 MW
No. 1.25 MW 402.5 MHz Klystrons	2
No. of 2.5 MW 805 MHz Klystrons	52
Physical Length of Linac	466 m
Linac Vacuum	$<1x10^{-7}$ torr
Linac Tunnel, Width x Height	14 x 10 ft
Beam-Floor Distance	5 ft

The linac vacuum requirement of $<1x10^{-7}$ torr is based on less than 1 nA/m beam loss at 1 GeV. Beam loss also drives the linac aperture, which varies from 2.5 to 4 cm diameter. The aperture is generally set to 10 times the rms beam size at higher energies. The aperture has recently been increased in the upstream structures to provide a negligible probability of beam loss. Additional linac design parameters are listed in Table 2.

* Work supported by the Office of Science, Basic Energy Sciences, of the U.S. Department of Energy; and the Oak Ridge National Laboratory.
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3 DRIFT TUBE LINAC

The lattice period for the DTL is 4 βλ at 402.5 MHz (equivalent to 8 βλ at 805 MHz). The design has recently been changed to a single tank design rather than a two-tank design. This eliminates the complexity of hardware design in the 1bl intertank region that would have included 2 end walls and beam diagnostics. The single tank shown in Figure 1 will be built up from 4 tank sections bolted together to make the 8.3 m long structure. The tank has 84 cells with 82 drift tubes with permanent magnet quadrupoles. The tanks are copper plated, thick-walled steel tubes in which the drift tube supports are integrated into the walls rather than relying on a separate girder support. The drift tubes are brazed and electron beam welded structures with stainless steel stems, copper bodies and samarium-cobalt permanent magnet quadrupoles. Post couplers are used to stabilize and tune the longitudinal field distribution.

RF power will be coupled to the tank via 4 drive loops. The peak RF structure power loss is 0.994 MW. The DTL will be water cooled and tuned by adjusting the coolant temperature according to feedback from the RF frequency measurement. During initial assembly, and prior to installation on the beamline, the structures will be aligned one tank section at a time using a pulsed taut wire system. Each tank section will be aligned to the next section by aligning the first drift tube only, then removing the upstream tank and aligning the remaining drift tubes in the downstream tank to the first. The DTL is in it's preliminary design phase with the preliminary design review scheduled for the end of FY '99. Prototype tanks sections are being machined and plated, prototype magnets are being built and prototype drift tubes will be built during the summer of '99.

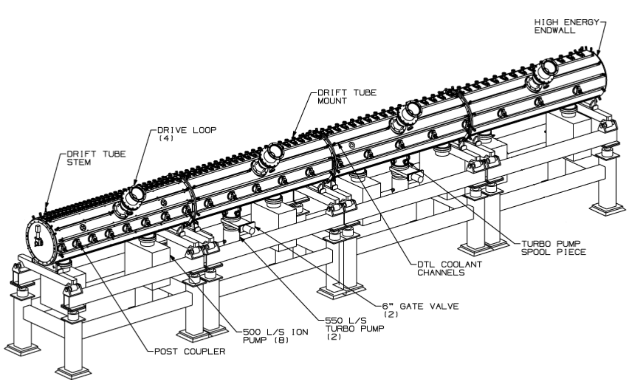

Figure 1: DTL Layout

4 COUPLED CAVITY DRIFT TUBE LINAC

The CCDTL consists of 91 segments and has a total length of 59 m. The segments are arranged into 2 RF modules, which are 33 and 26 m in length. The peak structure power loss is 6.5 MW. Each module is driven by 2 RF klystrons coupled to the structure with waveguide irises. The structure consists of 2 cells per segment, where a segment refers to a continuous brazed section of accelerating cavities between two quadrupole focusing magnets. Each accelerating cavity contains a drift tube. The lattice period for both the CCDTL and the CCL is 12 βλ.

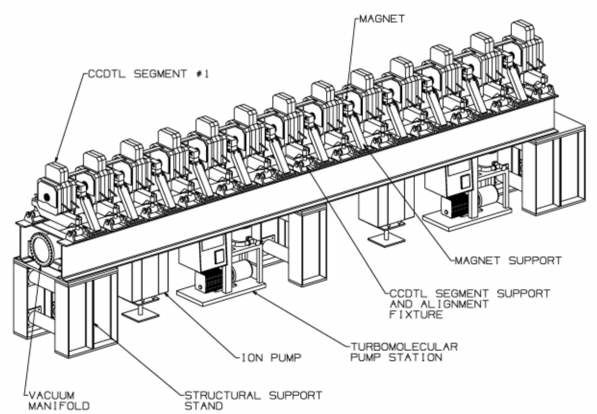

Figure 2: CCDTL Layout – Section 1 of RF Module 1

The CCDTL layout of the upstream end of the first RF module is shown in Figure 2. An electromagnetic quadrupole singlet is located between segments of RF structure. Beam diagnostic elements are also located in these intersegment spaces as necessary. These intersegment spaces are 6 βλ/2 in length and are spanned by long coupling cavities. The long intersegment coupling cells will be fitted with an internal tuning nose to provide for ease of disassembly. Because of the space needed for a magnet, diagnostics and vacuum flanges, special attention has been paid to this area. During the preliminary design, many refinements to the physics design have been made to provide additional spacing between the segments. In addition, special vacuum seals and flanges are being tested to minimize the space occupied by these components.

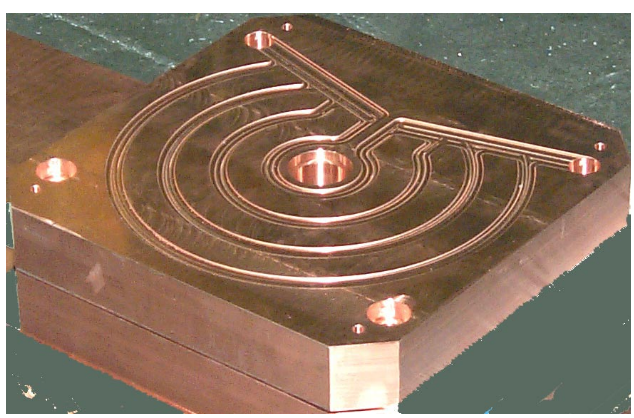

Figure 3: Septum cooling channel configuration

In achieving the desired accelerating gradient (3 MV/m), the copper power density has been pushed to the point that internal cooling of the cavity and drift tubes is required. The preliminary design has two cooling circuits, one for the bulk copper accelerator cavity and a second for the drift tubes. In order to minimize the temperature differential (and resultant stresses) in the structure, the septum between the accelerator cavities is provided with internal cooling channels. The current configuration for these cooling channels is shown in Figure 3.

5 COUPLED CAVITY LINAC

The bulk of the acceleration, 87 MeV to 1 GeV, takes place in the CCL. The CCL consists of 256 segments and has a total length of 399 m. There are 24 RF modules of which the longest is 19.8 m. The majority of the modules are between 15 and 18 m in length. Peak structure power loss in the CCL is 71.6 MW. The low energy portion has 8 cells per segment while the high-energy portion has 10 cells per segment. The intersegment spaces are 2 $\beta\lambda$ in the 8-cell CCL and 1 $\beta\lambda$ in the 10 cell CCL. This provides sufficient space for electromagnetic quadrupoles and diagnostics at all energies. All the coupled cavity structures use an even number of cells per segment so that the long intersegment coupling cells will be on the same side of the structure in order to simplify the mechanical design. Similarly, all intersegment spacings are even multiples of $\beta\lambda/2$ so that the coupling cavities are oriented parallel to the accelerator axis to simplify the mechanical design.

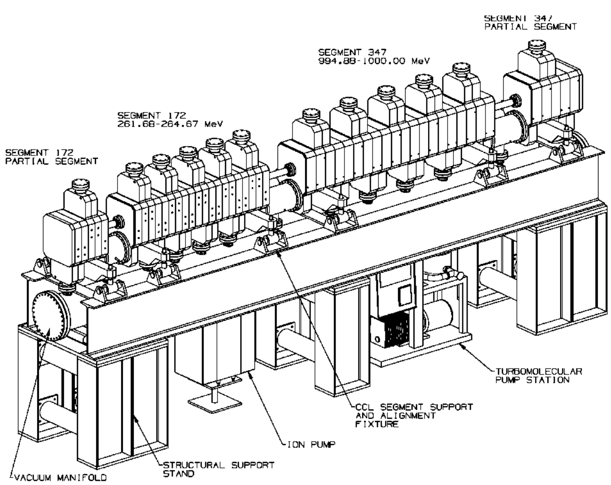

Figure 3: CCL Hot Model Layout

The major effort now is on modeling the structures. Cold models of the low and high-energy ends of the CCL are being fabricated and tested now and will be followed by construction of a hot model which is to be tested early next year. The layout of the hot model for the CCL is shown in Figure 3.

6 COUPLED CAVITY FABRICATION

There are numerous options for fabrication of the coupled cavity structures. One area of review is the extent to which vacuum brazing may be introduced in the plan in place of the historical Los Alamos choice of hydrogen brazing. Another area is the balance between industry fabrication and in-house Los Alamos fabrication. These options are under study with the evaluation parameters being: technical risk, schedule risk, overall cost, quality of the final product and transfer of manufacturing technology to industry.

The current fabrication plan for the structures utilizes capabilities both in industry and at Los Alamos. The material is OFE copper and we are in the process of qualifying material vendors prior to the large procurement of raw material. The key to fabricating these structures is to interleave the brazing processes with the RF tuning processes. Our plan is to machine, measure, and braze half-cells at shops in industry. The septum brazes required to create these half-cells are the critical water-cooling channel to vacuum brazes which will be accomplished using foil braze material. There will be approximately 2000 of these brazed subassemblies required for the CCDTL and CCL, including an allowance for scrap and rework. Once these feeder parts are completed, they will be shipped to Los Alamos for final tuning and stack brazing steps. Once the stacks are completed (2 cells for the CCDTL and 8 or 10 cells for the CCL, the RF structure subassemblies are ready to be assembled into the beam line assembly. Final assembly of the beam line elements will take place at the ORNL site.

The current preferred site for the SNS linac is the Chestnut Ridge site at ORNL. Due to the geology of the area, settlement of the building site has been a concern. This has required additional design effort in providing for the range of alignment features. In addition, the previously envisioned monument system in the building structure is being reviewed to determine if it is practical in this environment.

7 CONCLUSION

The mechanical design of the linac for the Spallation Neutron Source is proceeding into the preliminary design phase. During this fiscal year, numerous test pieces will be fabricated, cold and hot models will be fabricated and the overall manufacturing plan will be further developed.