COMPLETION OF CCL HOT MODEL FOR SNS-LINAC R&D PROGRAM *

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Abstract

Los Alamos completed the R&D program for the SNS linac in September 2002 with publication of a comprehensive report on the SNS coupled-cavity linac (CCL) hot model [1]. In this paper we summarize the results of this R&D program, including design of the bridge-coupled CCL, refinement of the design through cold models, and fabrication and testing of a hot model. We describe the RF system used to power the model, the prototype water-cooling and vacuum systems, and the experimental tests of these systems, including low-power, high-power, and radiation measurements. The CCL hot-model experiments answered vital questions about design, manufacturability, and stability for this type of RF structure.

INTRODUCTION

The Spallation Neutron Source (SNS) linac consists of four accelerating elements. A radio-frequency quadrupole (RFQ) accelerates the beam from an ion source to 2.5 MeV, a drift-tube linac (DTL) accelerates the beam from 2.5 to 87 MeV, a coupled-cavity linac (CCL) accelerates the beam from 87 to 185 MeV, and a superconducting radio frequency linac (SFF linac or SCL) accelerates the beam from 185 to 1,000 MeV. The linac R&D program at Los Alamos centered on designing and testing a representative segment of the CCL with full RF power. This program effectively tested both the physics and engineering designs of the cavity themselves, as well as prototypes of the vacuum, water-cooling, resonance control, and RF-power systems.

THE CCL HOT MODEL

A "hot model" is a powered section of a linac structure that is usually constructed as a prototype before major funds are committed for full construction. For SNS, the R&D program ran concurrently with much of the final design and procurement. To prove the concepts in time to influence manufacturing, we built a two-segment CCL hot model with prototype vacuum and water systems The purpose of the hot-model was to (1) confirm the physics design and manufacturing of the cavities, (2) verify the vacuum and resonance-control systems, (3) qualify vendors for procurement of CCL components, and (4) examine operational issues such as cold start, multipactoring, cavity conditioning, RF-field distribution under power, and thermal distribution. See [1] for details.

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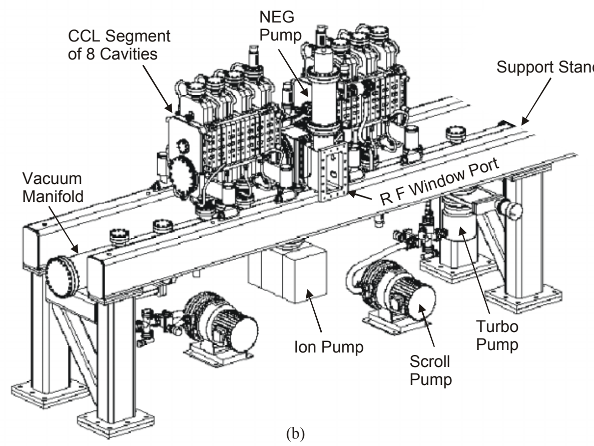

Figure 1. CCL hot model on support stand

CAVITY DESIGN

The SNS CCL requires relatively short accelerating segments compared to some previous CCLs to allow the frequent magnetic focusing required for high-current linacs. This requires resonant coupling (bridge couplers) between a large number of segments for efficient use of RF power. We used the cavity design code *Superfish* to design the shapes of the cavities and to compute surface fields, shunt impedance, and transit-time factors. The field contours shown in Fig. 2 for the TM_{010} mode are lines of constant magnetic field H, which are parallel to the electric field direction.

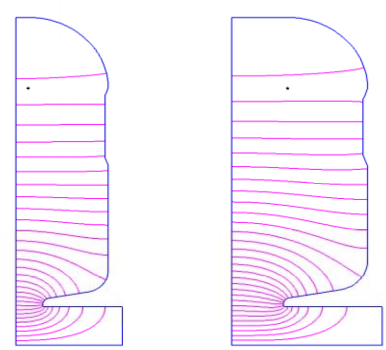

Figure 2. Superfish fields for CCL accelerating cells for $\beta = 0.40$ (left) and $\beta = 0.56$ (right)

In addition to the accelerating cavities, two types of coupling cavities and a bridge coupler cavity, which spans the space between two segments of the CCL structure, were required. One coupling cavity connects two accelerating cavities and the other connects an accelerating cavity to the bridge-coupler center cavity. To test the physics design, we built several "cold models" to determine the optimum shapes and coupling [2].

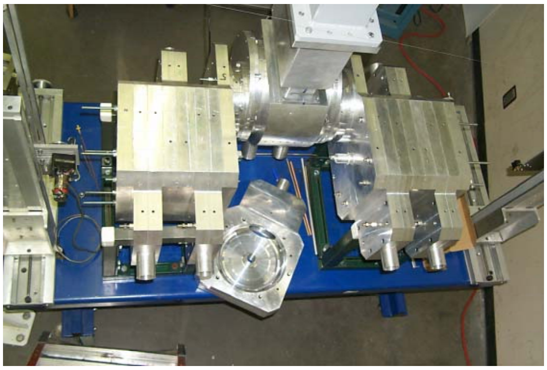

Figure 3. Example of cold model with bridge coupler

The mechanical design of the CCL hot-model cavities is described in [3]. The CCL is a multi-cell copper structure comprised of four modules, each made up of twelve segments. Each segment contains eight accelerator cavities or cells (see Figure below). For details of the fabrication process, see [4].

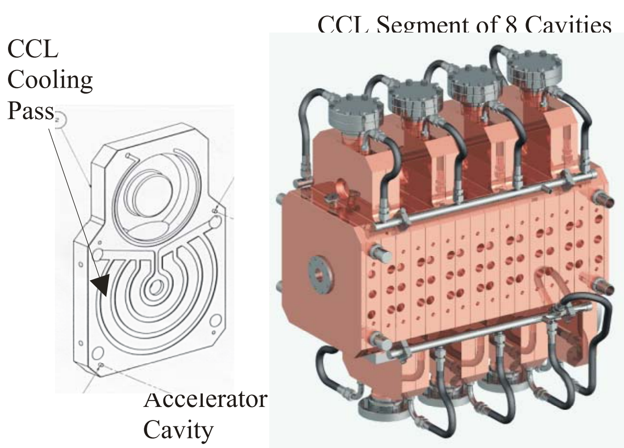

Figure 4. A CCL 8-cell segment with exploded view of the cooling passages

VACUUM SYSTEM

The four main goals of the vacuum experiments on the CCL hot model were (1) Determine if the vacuum system design could satisfy the vacuum pressure requirement of 9×10^{-8} Torr, (2) Measure gas composition of the vacuum environment, (3) Obtain empirical data to benchmark the numerical vacuum model, and (4) Characterize the vacuum conditioning process. To accomplish these goals, we did computer modeling to design the system and compared the experimental results with the model predictions. The results confirmed the design and gave us significant data important to final design of the CCL. See Ref. [1] for details.

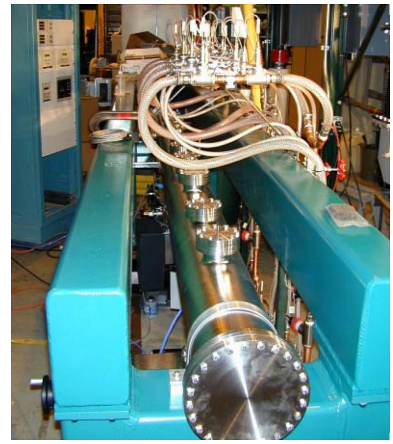

Figure 5. Hot-model vacuum manifold

WATER SYSTEM

The system that supplies the cooling water is equipped with a pump for coolant flow, a heat exchanger to cool the water, a heater to increase cavity temperature if needed, and a three-way valve to divert some of the water returning from the cavities through the heat exchanger while allowing the rest to recirculate [5].

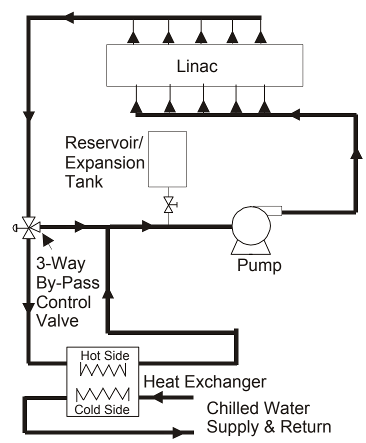

Figure 6. Simplified diagram of water-cooling system

The pump is run at a constant flow, and the flow rate into the cold side of the heat exchanger is also held constant. Many points, including surface temperatures, water temperatures, flow rates, the three-way valve position, forward and reflected RF power, as well as the RF error signal are instrumented and displayed by the control system. Numerical flow network models successfully predicted pressure drops within the CCL RF structure and water-cooling skid. See Ref. [1] for details.

RF POWER SYSEM

The 805-MHz RF system for the SNS linac was initially designed with 2.5-MW peak-power klystrons that used modulating anodes and isolated collectors. For the hot-model testes we initially used an existing modulator to provide power for the klystron, but it was limited in average power capability. Later in the experiment, we substituted the high-voltage converter modulator (HVCM), providing the initial test bed for this new technology. The 2.5-MW *CPI* klystron used for the hot-model tests exceeded all specifications and produced 2.5 MW within a few minutes of when it was turned on. It performed flawlessly during the hot-model tests. The complete hot-model RF-power system and its calibration are described in [1].

ASSEMBLY AND OPERAION

Following assembly, we made low-power RF measurements to tune the cavities. An axial bead-perturbation measurement showed a constant value of E0 to within ± 0.4% rms. See [1] and [4] for details.

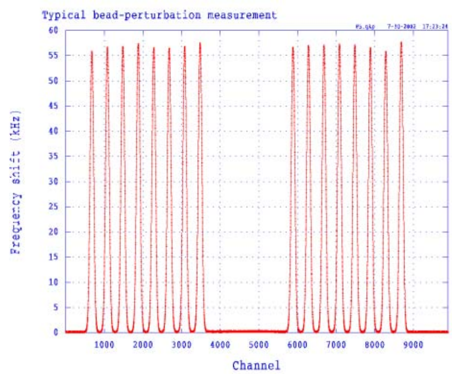

Figure 7. Bead pull measurement on hot-model cavity

We also measured the tilt sensitivity (or stability of the fields against frequency perturbations) by deliberately introducing end-cell perturbations. We raised the cell-1 frequency 160 kHz by pulling the end wall and lowered the cell-16 frequency 160 kHz by inserting a metal tube in the bore. A plot of the percentage difference in field between perturbed and unperturbed measurements showed the expected slope of ~+50 kHz [2].

Figure 8. Photograph of the bead-pull measurements being performed on the CCL hot model

An important goal of the hot model testing was to measure the stop-band gap at full RF-power operating conditions. To measure the stop band, we used the last 50 μs of the pulse to switch in a different RF generator whose frequency we could control. By observing the reflected power during this part of the pulse, we measured the frequencies of the two nearest modes to the $\pi/2$ mode. The stop band was slightly more positive at high power than at low power. The fact that these modes remain at very nearly the same frequency at different power levels indicates that cooling of the coupling cavities is well balanced with that of the accelerating cavities and that the stop band in the dispersion curve is not sensitive to the power level. See Ref. [1] for details.

Thermo-luminescence detectors (TLDs) were used to take measurements of the dark-current x-rays at a nominal power level of about 280 kW during a 1-hr run. The TLDs were placed directly above the O-ring on the flange joining the accelerating cavities to the powered bridge coupler. The readings ranged from 1.3 to 3.0 rad/hr. For an estimated SNS 40-year operating life, using 24-hr/day and 300 days/year, the highest reading of 3 rad/hr is equivalent to 0.9-megarad accumulated dose. Since *Viton* O-rings have an estimated radiation tolerance of at least 20 megarad, these measurements indicate that SNS should have no trouble with this use of O-rings in the CCL.

SUMMARY

We met or exceeded our principal goals of demonstrating that the CCL RF structure could be tuned and operated in a stable manner at required power levels. We developed a manufacturing process and a comprehensive tuning plan to be used by industry [4]. We were able to test much of the SNS prototype hardware in an integrated test, including the vacuum system, water-cooling and resonance-control system, the HVCM, the 2.5-MW prototype klystron, and the bridge-coupled CCL structure. This experience has allowed us to anticipate some of the problems that LANL and ORNL will face as we test and commission the CCL at Oak Ridge.

ACKNOWLEDGEMENTS

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