BRIDGE COUPLER THERMAL/STRUCTURAL ANALYSIS AND FREQUENCY SHIFT STUDIES FOR THE COUPLED CAVITY LINEAR ACCELERATOR OF THE SPALLATION NEUTRON SOURCE *

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Abstract

The Spallation Neutron Source (sns) is an accelerator-based neutron scattering research facility. The linear accelerator (linac) is the principal accelerating structure and divided into a room-temperature linac and a superconducting linac. The normal conducting linac system that consists of a Drift Tube Linac (DTL) and a Coupled Cavity Linac (CCL) is to be built by Los Alamos National Laboratory.

The CCL structure is over 55 meters long. It accelerates H beam from 86.8 Mev to 185.6 Mev at operating frequency of 805 MHz. This side coupled cavity structure has 8 cells per segment, 12 segments per module, and 4 modules total. The bridge coupler with length of $2.5 \beta \lambda$ is a three-cell structure and located between the segments and allows power flow through the module. The center cell of each bridge coupler is excited during normal operation. There is total 44 bridge couplers included 8 of them used as the RF feed locations. To obtain a uniform electromagnetic filed and meet the resonant frequency shift, the RF induced heat must be removed. Thus, the thermal deformation and frequency shift studies are performed via numerical simulations in order to have an appropriate cooling design and predict the frequency shift under operation. The center cell of the bridge coupler also contains a slug tuner and a post tuner that used to provide bulk frequency adjustment and field intensity adjustment, so that produce the proper total field distribution in the module assembly. Thermal analyses and estimate of frequency-adjusted levels to help guide the cooling design are also proceeded.

1 INTRODUCTION

The Spallation Neutron Source (SNS) is an accelerator-based neutron source that produces pulsed neutron beams by bombarding a mercury target with intense beams of 1-GeV protons. It is being designed to meet the needs of the neutron scattering community in the United States well through the 21st century. The SNS is scheduled for completion in December 2005 at Oak Ridge National Laboratory (ORNL).

The Project is being carried out by a multi-laboratory collaboration, led by ORNL and comprised of five other National Laboratories. Los Alamos National Laboratory (LANL) is one of them, and responsible for design and construction of the room temperature linear accelerator

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and to adequately reduce induced thermal stress levels in
the system.
To guide the cooling system design, studies of the
thermal performance, associated induced stress levels and
frequency shift have been performed via numerical
simulations.

2 RF HEATING AND COOLING SCHEME
The SNS bridge couplers are 3-cell co-axial structures
of $2.5-\beta\lambda$ total lengths. Only the center cell is resonant.
The center cell length is fixed for all 44-bridge couplers.
The lateral coupling cell lengths increase with increasing
energy. Each bridge coupler joints two CCL segments,
coupling them together forming a multicavity accelerating
structure. The two end cells are connected to the center
cell via slots in the divider plates. Thus, the bridge
coupler accommodates RF power transmission from one
segment to the next with proper phase matching. Presence
of the resonant electro-magnetic fields creates electrical
currents on the interior skin of the coupling cell and thus
deposits thermal energy into the cell wall that causes
thermal distortions which result in a resonant frequency
shift and induced stresses.
Under normal operation, about 670 watts of RF power
at 7% design duty factor is dissipated in the center cell
walls for the first bridge coupler. To achieve the desired
resonance frequency, the bridge coupler is actively water-
cooled with four copper 3/16 in. diameter tubing lines
brazed to grooved channels on the external surface of the
unit. This provides a simple method for heat removal. The
channels are depicted in Figure 3 of the three-dimensional
numerical simulation model.

3 FREQUENCY SHIFT STUDIES
The thermal distortions caused by RF heating result in a
frequency shift because the shape of the cavity changes.
The magnitude of the frequency shift of any given cavity
can be calculated using the Slater- perturbation theory.
The change in frequency $df$ is a function of the volume
change of an infinitesimal volume $dV$ at the RF surface, as
well as the magnetic and electric fields, $H$ and $E$ on the
surface and cavity stored energy $U$. The frequency shift is
given by:

$$df = \frac{\int (\mu H^2 - \varepsilon E^2) dV}{4U}$$

where $\mu$ and $\varepsilon$ are the free space permeability and
permittivity, respectively, $f$ is the cavity unperturbed
electromagnetic resonance frequency. For the bridge
coupler, the deformation of the bridge coupler wall, nose
plate, and septum plate all contributes to the total
frequency shift.
To accurate frequency-shift, a code that links
SUPERFISH and COSMOS/M [1] has been used for the
study. A two-dimensional axisymmetric model for the
first bridge coupler of $0.404 \beta$ has been generated with
heat loads calculated by SUPERFISH [2]. The
axisymmetric elements simulate the cell radial and
longitudinal growth. The thermal deformation
corresponding to the temperature profile is calculated with
the heat transfer solver of COSMOS/M code. A
frequency shift of $-54.1$-kHz has been calculated for this
bridge coupler. The cavity deformation is depicted in
Figure 5.
Note that the heat load of the axisymmetric 2-D model does not include the additional heating due to the coupling slots. The calculated maximum temperature rise for the 2-D model is 1.1°C lower than the calculated value for the 3-D model.

4 COOLING OF SLUG TUNER

The slug tuner is 3-inch diameter solid copper cylinder brazed to a stainless steel flange, as shown in Figure 6.

Figure 6: Slug tuner of the CCL bridge coupler.

It is installed in the center cell of each bridge coupler to allow adjustment of the cavity RF frequency. A maximum penetration depth is 1.5 inches for the current design. The heat load on the slug tuner surface depends on electromagnetic field, cavity stored energy values, RF surface resistance, and the slug tuner penetration depth. The calculation is performed using a safety factor of 2 with respect to thermal loads, and 7% RF duty factor. Total power dissipated on the slug tuner surface is 52-watts [3]. A nominal heat flux of 0.40 w/cm² is used for the thermal simulation. A Cooling channel is situated in the copper cylinder with 0.25 inch-width and 0.1-inch depth. The coolant inlet and outlet are 36° apart with respect to the slug tuner’s axis and are located within the 304L stainless steel mounting flange. Using a mass flow rate of 0.5 gpm, the corresponding heat transfer coefficient was applied on the edges of cooling channel to simulate the forced convection boundary condition. The results of the thermal analysis using 2-D and 3-D finite element models predict a temperature rise on the penetrating portion of the slug of 2°C. The frequency shift due to the surface heating is only 6-7 kHz.

5 STRUCTURAL ANALYSES

Considering the location of all bridge couplers and the difficulty of installation and maintenance, symmetry COSMOS/M finite tetrahedron element model of the bridge coupler has been constructed to evaluate bridge coupler structure rigidity and stiffness. The cavity is made of OFE copper, while the flanges are made of stainless steel. The loads are applied to the flanges. The loading cases are shown in Figure 7. The analysis results are listed in Table 1.

6 CONCLUSIONS

This report is for the provided physics and mechanical design of the bridge coupler at the Coupled Cavity Linac Preliminary Design Review. The bridge coupler is being fabricated for the CCL hot model test. The cooling scheme and parameters are defined for the bridge coupler system. The value of frequency shift is in the tunable region. From a practical standpoint, each bridge coupler will be tuned during final assembly to a pre-determinable frequency to give a nominal 805 MHz resonance at powered operation. The mechanical design of the CCL is proceeding into the final design review. Upon the frequency-tuning request, the mechanical design of the bridge coupler needs further modification. The thermal/structural analysis and the frequency shift study for the bridge coupler with RF feed will be performed. The assembly of the bridge couplers is very critical due to the locations. An extreme caution and special equipment will be needed to avoid from detuning the bridge couplers.

7 REFERENCES