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Title: Bridge-Coupler Thermal/Structural Analysis and Resonant Frequency Shift Studies for the SNS CCL

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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 21^{st} 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 (Linac), while Jefferson National Laboratory builds the superconducting Linac. The normal conducting linac consists of a drift-tube linac (DTL) and a coupled-cavity linac (CCL). The total length of CCL section is 55.36-meters. It accepts beam from the DTL at 87-mev and delivers it to the superconducting accelerator at 185.6-mev. It operates at a radio frequency (RF) of 805 MHz. the CCL has 4 modules. A 5MW klystron is utilized for each module that consists 12 segments and 11 bridge couplers. The number 3 and number 9 bridge coupler of each module are connected to the 5-MW RF power supply. The feed is through a slot iris in the center-powered cell. Figure 1 shows the two types of bridge couplers.

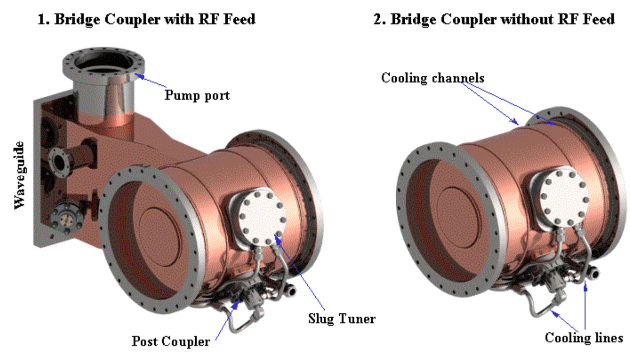

Figure 1: CCL Bridge Couplers.

The bridge couplers are supported from the adjacent CCL segments and are free to axially expand or contract with the segments, as shown in Figure 2.

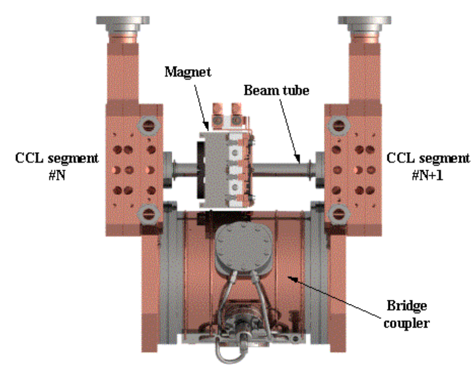

Figure 2: Bridge Coupler Location between segments.

RF power is dissipated in the resonant center cell walls. The thermal expansion that results from RF heating causes the resonant frequency shift and mechanical loading of the structure. A cooling system has been designed to mitigate the affects of the RF frequency shift

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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-βλ 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.

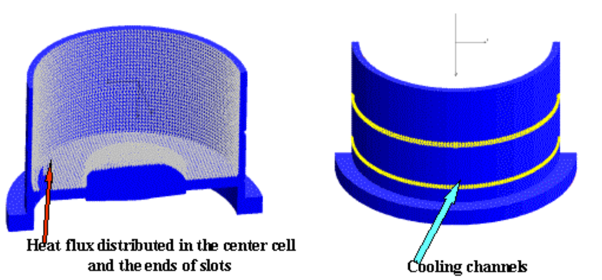

Figure 3: RF heating and cooling scheme.

Taking advantage of the bridge coupler symmetry, a three-dimensional finite element model of a quarter bridge coupler with 0.404 β was created using COSMOS/M, a structural/thermal finite element code. The applied variable heat fluxes on the inner wall, septum plate, and nose plate of the center cells are calculated with the physics code SUPERFISH. A 5% safety margin has been added to the calculated heat loads. Additional power is added numerically at both slots ends to accurately simulate slot edge heating affects. This corresponds to a heat flux that is 16 times greater than that of the nose plate surface. Inlet cooling water of 20^0C at a flow rate is 0.25-gpm through each cooling channel, which corresponds to a water velocity of 2.0-m/s, is utilized. Water-cooling within the numerical model is simulated by a forced convection boundary condition with heat transfer coefficient of 1.08 w/cm^{0}K. The hottest area occurs at the slot edges; the maximum von Mises stress occurs at the slot ends. The temperature profile and the thermal stress contour resulting from RF heating for the bridge coupler are shown in Figure 4.

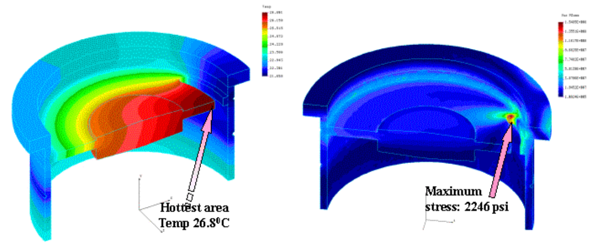

Figure 4: Temperature and von Mises stress contours.

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:

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

where μ and ε 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 β 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.

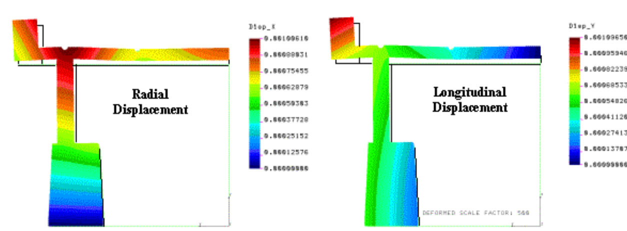

Figure 5: Bridge coupler thermal Displacement profiles.

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^{0}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.

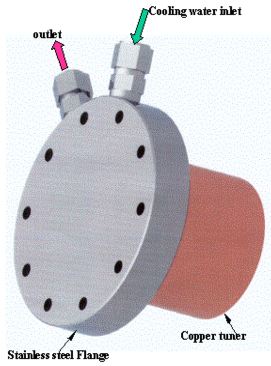

Figure 6: Slug tuner of the CCL bridge coupler.

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/cm^2 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 36^0 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^{0}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.

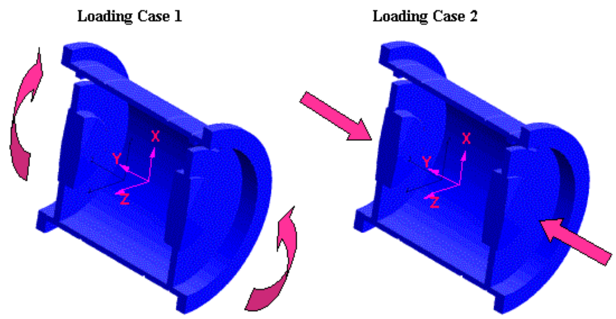

Figure 7: Bridge coupler loading cases.

Table 1: Results of the Bridge Coupler Structural Analysis

Loading direction	Stiffness	Limit Load
Rz	3.14E5 in-lb$_f$/mr	3,117 ft-lb$_f$
Rx	3.14E5 in-lb$_f$/mr	3,117 ft-lb$_f$
Y	4.67E7 lb$_f$/in	34,770 lb$_f$

6 CONCLUSION

This report documenting the physics and mechanical design of the bridge coupler was compiled for the CCL Preliminary Design Review. One bridge coupler is presently being fabricated for testing with the CCL hot model test. The mechanical design of the CCL is proceeding toward its final design review.

The assembly and installation of the bridge coupler is critical due to very limited access and the high potential for damage to the bridge coupler and the two adjoining CCL segments. Special equipment and precise installation procedures and techniques will be needed to avoid damage to the bridge couplers or adjoining hardware

7 REFERENCES

[1] Wood, R. L. AOT –1 Los Alamos National Laboratory, March 2, 1995.

[2] Billen, J. H., "Bpc1.am" and "Bpc1.sfo", LANL, October 18, 2000.

[3] Chen, Z. "CCL Slug Tune Thermal Analysis and Thermally Induced Frequency Shift Calculations" SNS_TCN_0249, LANL, October 6, 2000.