

THE FUNDAMENTAL POWER COUPLER PROTOTYPE FOR THE SPALLATION NEUTRON SOURCE (SNS) SUPERCONDUCTING CAVITIES*

I. E. Campisi[†], E. F. Daly, J. E. Henry, P. Kneisel, W. J. Schneider, M. Stirbet, K. M. Wilson
TJNAF, Newport News, VA 23606, USA

Abstract

The SNS linac contains superconducting cavities with β .61 and .81 for the acceleration of H⁺ ions. Each of the 6-cell cavities, resonant at 805 MHz at 2.1 K, is powered by a 550-kW pulsed klystron via a coaxial coupler. The specifications for the fundamental power coupler (FPC) require that it withstand the full klystron power in full reflection for the duration of the RF pulse (1.3 + 0.15 [decay] ms) at a repetition rate of 60 pps with an average power of 48 kW. The FPC must provide a Q_{ext} of 7.3×10^5 and 7.0×10^5 for the medium- β and high- β cavities, respectively. A design derived from proven experience at other laboratories (primarily at KEK, for Tristan and KEK-B cavities at 508 MHz) has been adopted for the prototypes of the FPCs. The 50- Ω coaxial line is scaled directly from 508 MHz to the SNS frequency of 805 MHz.

1 INTRODUCTION

The Spallation Neutron Source makes use of superconducting RF cavities resonating at 805 MHz in the fundamental $TM_{010}-\pi$ mode to accelerate H⁺ ions in the main linac from 185 MeV to the full final energy (840-1300 MeV) [1].

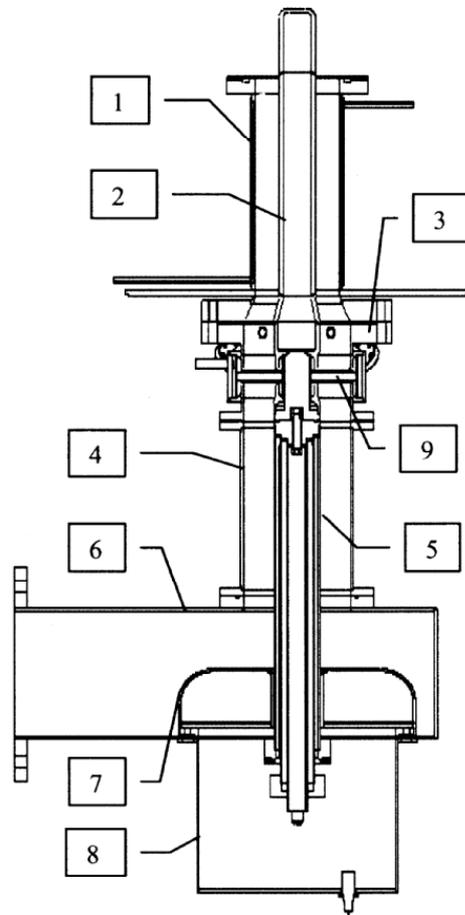
The superconducting cavities, under development at Jefferson Lab [2], must produce accelerating gradients consistent with peak surface electric fields of 27.5 MV/m, or better. In order to power the cavities, coaxial couplers were chosen. The couplers must be able to withstand at least the peak power delivered by the SNS klystrons (shown in Table 1), 550 kW for a 1.3-msec pulse length at a repetition rate of 60 pulses per seconds (pps).

Table 1: Coupler requirements

Parameter	Operation	Processing
Q_{ext}	7×10^5	NA
Impedance	50 Ω	
Peak power	550 kW	1 MW
Pulse length	1.3 ms	1.3 + ms
Repetition Rate	60 pps	60 pps
Average power	48 kW	60 kW (cooling limit)
Bias	± 2.5 kV	± 2.5 kV

A simple window geometry was chosen to facilitate manufacturing and assembly. The experience of KEK in

the use of couplers of similar geometry for Tristan and KEK-B had demonstrated that high power could be reached with short conditioning times [3]. The KEK couplers had reached close to 1 MW in CW during conditioning and close to 400 kW in operation. To adapt that design to the SNS frequency, a geometrical scaling of the coupler's main dimensions with frequency was implemented. The FPC design is shown in Figure 1.



- 1 – Outer Conductor
- 2 – Inner Conductor
- 3 – Window Assembly
- 4 – Outer Extension
- 5 – Inner Extension
- 6 – Waveguide
- 7 – Doorknob
- 8 – Waveguide Cover
- 9 – Ceramic Window

Figure 1: Fundamental Power Coupler.

By this method, several properties would remain invariant, including the impedance and the multipacting

* Supported by US DOE Contract No. DE-AC05-00OR22725

[†]campisi@jlab.org

levels in the coaxial part of the FPC [4]. However, some of the constraints imposed by the cryomodule geometry and assembly procedures led to a number of design modifications.

Below are discussed the main characteristics of the FPC design and some of the design calculations. The results of the preliminary tests performed on the prototype FPCs are presented elsewhere [5].

2 ELECTRICAL AND RF DESIGN

2.1 Coaxial Line and Window

The design of the SNS prototype FPCs relies on a simple coaxial line at 50 Ω . The planar alumina window includes impedance-matching elements [3, 6] as well as TiN anti-multipacting coating. This component is critical for the success of the FPC's performance, so a great deal of attention has been put into the reliability of the design and the production quality controls.

2.2 Waveguide-Coaxial Transition

The transition between the WR975 waveguide from the klystron and the coaxial line of the FPC is provided by a doorknob configuration [4].

2.3 Multipacting and Voltage Bias

Multipacting in the coaxial line and at the window can produce window limitations and failures. Extensive simulations have been performed to study the multipacting behavior of the FPC and the levels and locations have been predicted [4]. The FPC includes the possibility of biasing the inner conductor via a capacitor gap between the doorknob and the inner conductor itself at variable voltages between -2.5 and $+2.5$ kV. The gap is filled with Kapton[®] foil, which is capable of withstanding the biasing voltage.

2.4 Coupling

One critical parameter which the FPC must be able to meet is the Q_{ext} . Again, extensive simulations and measurements have been performed and reported [4].

The Q_{ext} can vary due to the following reasons:

- The thermal contraction of the outer conductor and the thermal expansion of the inner conductor during full power operation (as much as 48 kW average power). This effect is estimated to alter the Q_{ext} by no more than 10%.
- Mechanical tolerances of the FPC's inner and outer conductors. Due to these variations, the Q_{ext} should vary by no more than 10%.
- Line mismatch in the window assembly and in the door knob transition. The total VSWR is estimated to be around 1.05, so that variation of Q_{ext} would amount to about 5%.
- Uneven field profile in the cavity. This effect is currently under study. Since few statistics are

available, this effect is estimated to be around 40%.

2.5 RF Losses

The average RF dielectric losses in the window are estimated to be around 2 W, whereas the losses in the transmission line are 30 W in the inner and 3 W in the outer conductor, between the window and the FPC's tip. These losses can be easily handled by the cooling system described in section 4.

3 MECHANICAL DESIGN

Once the FPC is fully installed, it is expected to be subjected to minimal mechanical loads other than the structural requirement that it be able to support its own weight, the thermal contractions and expansions of the outer conductor that may be induced by temperature fluctuations, and the force imposed by the pressure differential between the atmosphere and the vacuum.

The weight of the extensions, waveguide, doorknob and cover is about 9 kg. This weight is primarily conveyed through the outer extension of the FPC to the outer conductor portion of the window and to the cryomodule. In addition, a support bracket bolted to the outside of the cryomodule will be supporting some of the weight of the FPC assembly.

The total thermal contraction of the outer conductor as it ranges from room temperature to 2 K is 0.4 mm. The FPC is designed so that the compliance in the bellows between the coupler and the cryomodule will compensate for this deflection. Another load will be produced by the pressure of the atmosphere on the large flange of the outer conductor when the space inside the cryomodule is evacuated. This force, distributed about the thinnest cross-sectional area of the outer conductor, would cause a negligible compressive stress of 30 MPa; the Von Mises bending stress on the beam pipe to which the FPC is attached is only 12 MPa.

During assembly, a concern is the possibility of damaging the window, which would be most likely to occur during attachment of the inner extension. However, an analysis of the assembly shows that when the inner extension is deflected, the fragile window area is not the location of the highest stresses (Figure 2); instead, noticeable yielding of the window-inner extension joint would occur before damage to the window region.

To verify that the coupler assembly is not excited by the macropulse repetition rate of the accelerator, which is 60 pps, a normal modes analysis of the assembly was performed. When the FPC is mounted in the cryomodule, the inner conductor is supported at the window and thus acts like a cantilever. The calculated fundamental frequency of the assembly is 97 Hz, above the range of concern.

Two prototypes of the FPC have now been successfully assembled and tested under vacuum without any damage to the components.

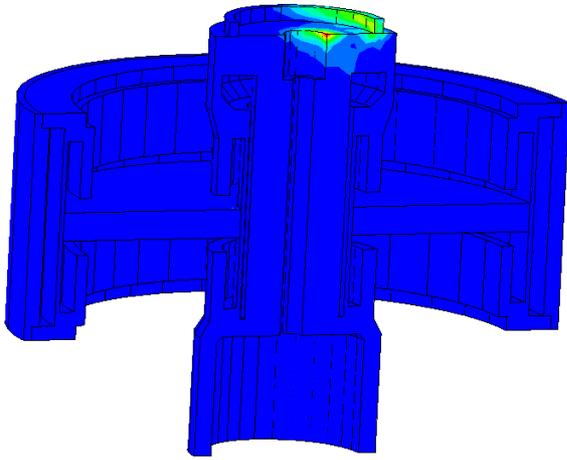


Figure 2: Stress contours on window assembly.

4 THERMAL DESIGN

To minimize heat transfer to the cavity beampipe, the FPC outer conductor is helium cooled. By design, the total heat load, including static and dynamic contributions, from the FPC to the 2K circuit must be less than 2 W. To handle these loads, a stream of 3 atm, 5 K supercritical helium with a flow rate of 0.038 g/s per FPC removes ~30 W of static and dynamic heating during normal operation. As shown in Figure 3, a heater-thermocouple control loop maintains the window at 300 K while the cold end operates at ~5K.

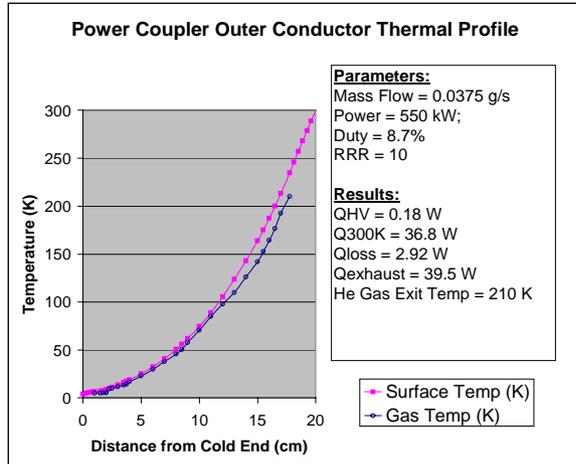


Figure 3: FPC outer conductor thermal profile.

A single helical, square-grooved flow passage is machined into a thick-walled stainless steel tube. A thin-walled stainless steel tube is then shrunk-fit over the outer diameter of the flow passages and welded leak-tight onto the ends nearest the flanges.

The internal vacuum surface is copper plated with a nominal thickness of 15 μm (RRR=10) to reduce resistive wall losses induced by the RF surface currents while minimally increasing the heat load to the 2 K circuit.

In addition, the inner extensions are water cooled to remove heat from the inner conductor and reduce radiative heating of the cavity beam pipes. A system was

designed in which water enters through the outer of three concentric tubes and exits through the middle tube (the inner tube being hollow and air filled). The stream of water passes near the inner conductor-inner extension interface and removes the heat which is conducted through the inner conductor.

A thermal analysis was performed to determine the minimum acceptable water flow rate. The window was modeled axisymmetrically; it was assumed that 30 W would be transmitted from the inner conductor to the inner extension cooling circuit, and that an additional 62 W/m would be generated along the length of the inner extension. Initially, it was assumed that the water would be stagnant, a worst case scenario. Even with conduction the only method of heat removal, the temperature rise from the water inlet to the copper window was under 2 K.

5 CONCLUSIONS

The prototype FPC for the SNS superconducting cavities is based on a design scaling from the KEK coupler. Simple changes have been implemented to adapt the FPC to the design requirements of the SNS cryomodule. Preliminary testing of the first two FPC prototypes has indicated that there are no significant design problems.

6 ACKNOWLEDGEMENTS

The authors wish to thank J. Henry, T. Whitlatch, B. Carpenter, K. Macha, L. King, S. Castagnola, J. Brawley, L. Turlington, R. Bundy, C. Apeldoorn, T. Elliott and W. Sommer for the essential assistance in designing and fabricating the fundamental power coupler prototypes.

7 REFERENCES

- [1] T. E. Mason, "The Spallation Neutron Source: A Powerful Tool for Materials Research," PAC2001, Chicago, IL, June 2001.
- [2] G. Ciovati et al., "Superconducting Prototype Cavities for the Spallation Neutron Source (SNS) Project," PAC2001, Chicago, IL, June 2001.
- [3] S. Mitsunobu et al., "High Power Input Coupler for KEKB SC Cavity," 9th Workshop on RF Superconductivity, Santa Fe, NM, November 1999.
- [4] Y. Kang et al., "Electromagnetic Simulations and Properties of the Fundamental Power Couplers for the SNS Superconducting Cavities," PAC2001, Chicago, IL, June 2001.
- [5] M. Stirbet et al., "Testing Procedures and Results for the Spallation Neutron Source Fundamental Power Coupler," PAC2001, Chicago, IL, June 2001.
- [6] W. R. Fowkes et al., "1.2-MW Klystron for Asymmetric Storage Ring B-Factory," PAC95, Dallas, TX, May 1995.
- [7] Randall F. Barron, *Cryogenic Systems*. 2nd Ed.