THE POWER COUPLER DESIGN FOR THE APT SUPERCONDUCTING ACCELERATOR

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INTRODUCTION

Recent proposals for high-current cw proton accelerators acknowledge the importance of superconducting technology for cost-efficient and reliable operation. Los Alamos National Laboratory is working on the design of a facility that accelerates a 100mA proton beam to a final energy of 1.7GeV. In our design, using 5-cell superconducting cavities for the major part of the accelerator requires delivery of up to 420kW of rf power into a single cavity. Presently used power couplers, in operation with beam, have never been used in this power regime. Our choice of using two couplers per cavity allows us to reduce the required level to 210kW, a reasonable extension of today's operation experience. This is a report of the design choices we made, our design effort using state-of-the-art electromagnetic modeling tools, and of low power tests we did on a few of the coupler components.

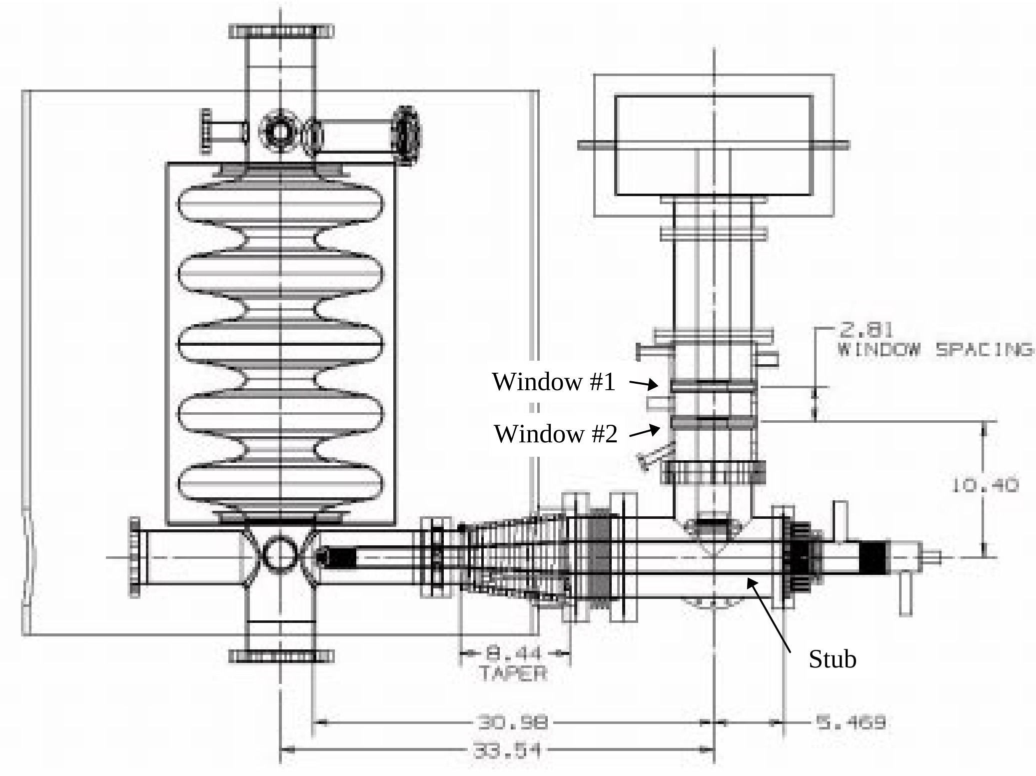

Fig. 1:A Schematic Layout of the Coaxial Window and Coupler

GENERAL LAYOUT

Based on experience in recently developed superconducting-accelerator applications (DESY, CERN, KEK) and high-power window operation in klystrons we opted for the use of a coaxial coupler and window (Fig. 1). The power coming from the klystron by a wave-guide is transferred to the coaxial line by a wave-guide to coax T-bar transition. This transition is in a horizontal orientation, parallel to the beam axis. In the same line there is a warm double window, providing the air to vacuum separation. After the window a quarter-wave-stub provides a transition to the coaxial line that guides the power towards the cavity. This transition also contains a rf matching device (collar), and a vacuum pump-port. In this part of the line the outer coaxial diameter is tapered down from 6 1/8 to 4 inches to provide a tube size at the cavity side that is compatible with the beam pipe sizes. The tip of the center conductor also includes a bellows that provides some adjustment for the range of external Q as well as for a symmetric operation of the two opposing couplers attached to one cavity. The entire coupler assembly is parallel to the ground, to avoid the possibility of dirt falling onto the windows, or from the coupler into the cavity area.

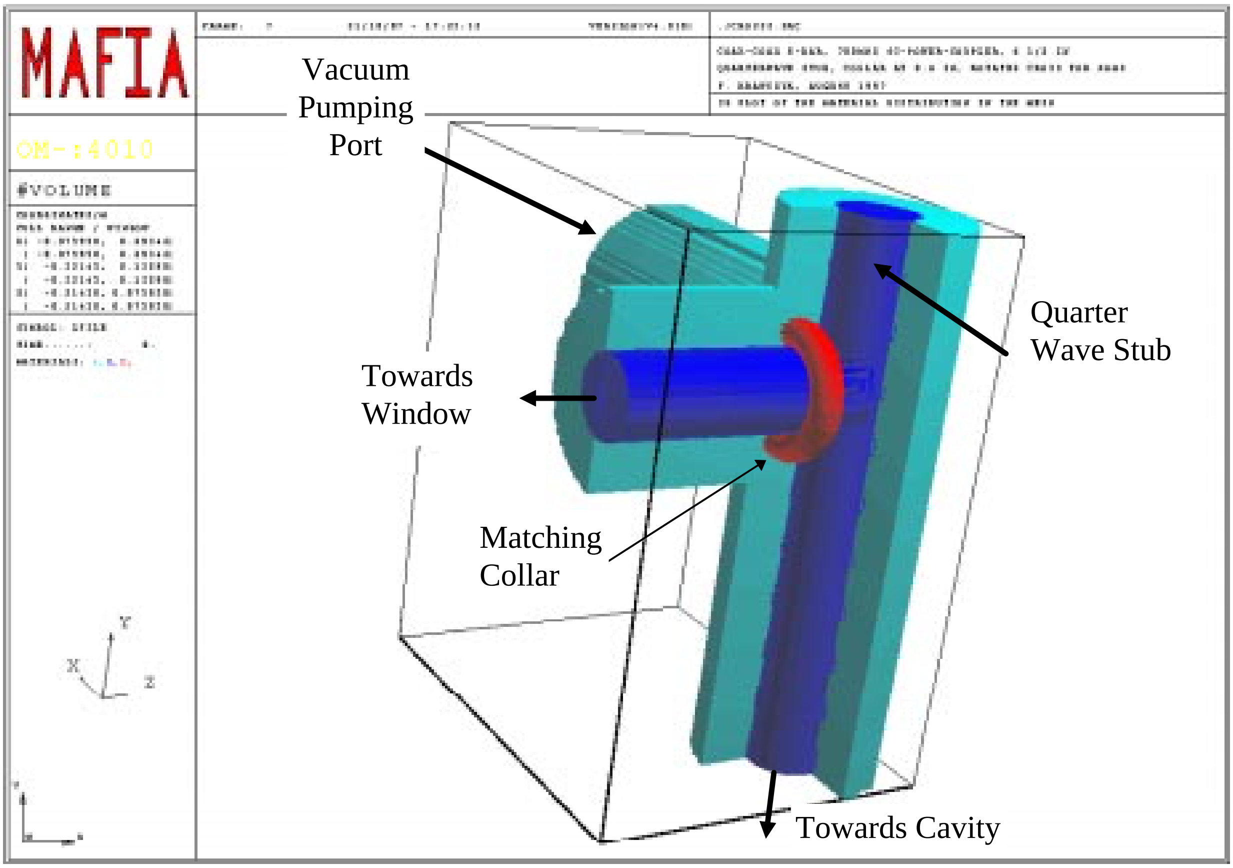

Fig. 2: A MAFIA Model of the Quarter-Wave-Stub and a Matching Device (The y-z plane is oriented horizontal)

THE WARM DOUBLE WINDOW

The coupler window is a warm double window outside of the cryostat. The coaxial line at this point of the coupler has a 6 1/8 inch diameter. This size is driven by the good experimental experience we had in testing a 350MHz window of the same type up to 950kW power[1]. This 350MHz window will be used for the RFQ in the normal-conducting low-energy part of the accelerator. Both sides of the window on the klystron side (window #1 in Fig. 1) are in air. The air in the space between the two windows is added for cooling and homogenizing the temperature on window #2. The cavity side of window #2 is under vacuum. The distance between the two windows is $\lambda/6$ ($\lambda \approx 42$cm at the operation frequency of 700MHz.) This window separation is driven by simulation results under different operating conditions (traveling and standing wave) [2]. These simulations also determined the position of the window in the line.

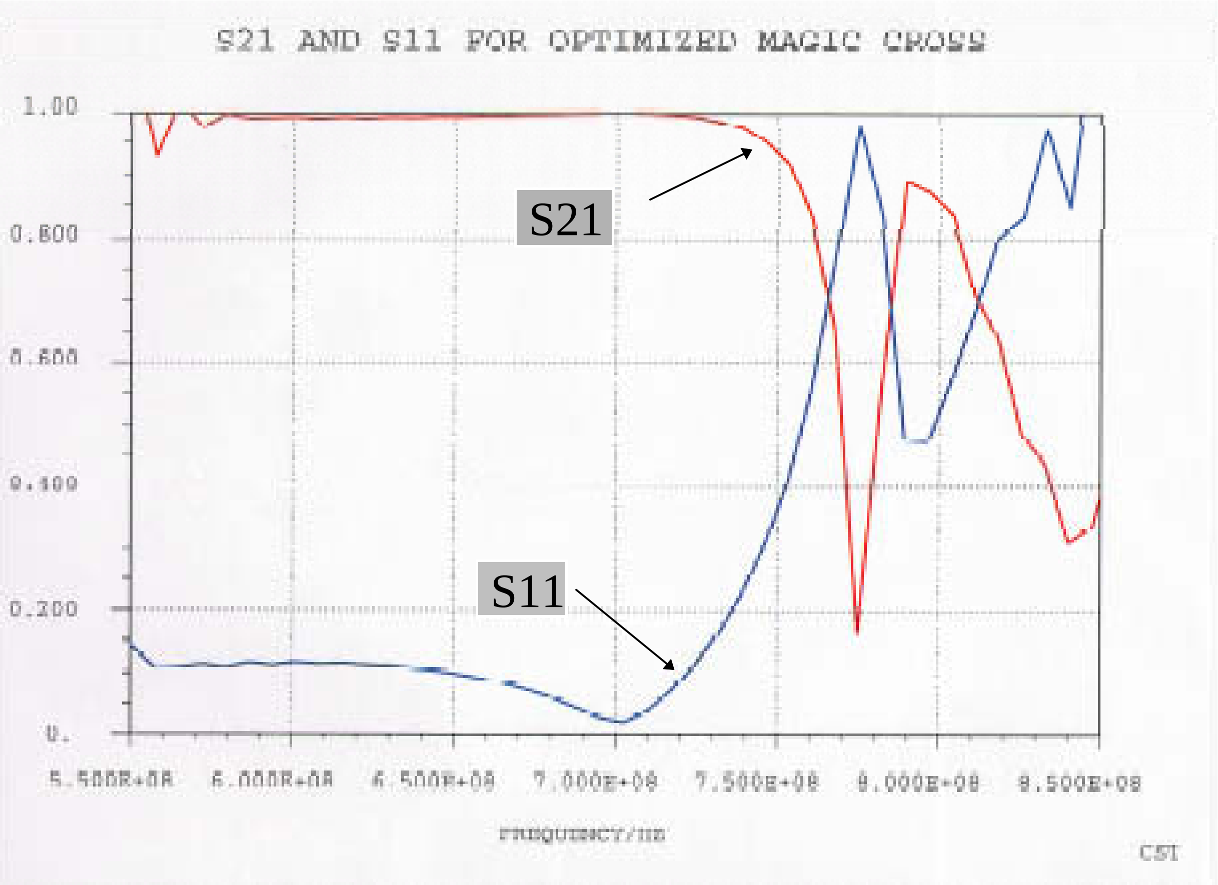

Fig. 3: Transmission and Reflection through the Quarter-Wave-Stub

THE QUARTER-WAVE-STUB

The coaxial T-shaped transition that guides the power from the klystron towards the cavity is a mismatch in the 50Ω coaxial line. To compensate for this mismatch, a quarter-wave-stub and an additional matching collar are added at the transition (see Fig. 2). This design has several advantages. It allows a clear separation between the window and the coupler part in fabrication and assembly, it allows for a simple coupling adjustment by moving the tip of the center conductor by the cooling tube inside the conductor. It also makes it simpler to feed cooling liquid or air to the center conductor and it adds to the rigidity of this center conductor. The length of the quarter-wave-stub and the position of the matching collar determine the achievable power transmission. The VSWR needs to be between 1.05 and 1.1 over a bandwidth of ±10MHz with the best match at the 700MHz operating frequency. Electromagnetic simulations have been used to get an estimate of the geometric dimensions of the quarter wave stub and of the position and size of the matching collar. Fig. 3 gives the result of a broadband simulation with the MAFIA electromagnetic simulator for a stub and collar arrangement that fulfills the requirements. Another feature in the stub region is a vacuum pump-port (see Fig. 2.) The pump-port's main purpose is to provide a good vacuum on the cavity side of the double window. This seems to be an important feature for reliable coupler operation [3,4]. Another driver for adding this port, the removal of HOM-power traveling in the coaxial pipe has been dropped; an estimate of the HOM-power [5] indicates that compared to the operational power levels of more than 200kW this contribution (less than 20W) can be neglected. The position and orientation of the pump-port is driven by the available space in the cryostat layout and by simulated return losses achieved using different port orientations and numbers of ports. Besides the broad-band transmission characteristics of the quarter-wave-stub, the electromagnetic fields and losses in the stub and matching region have also been evaluated. For this the traveling wave fields in the stub region at the 700MHz operating frequency are calculated. Then the real and imaginary part of the electric and magnetic field components are stored and used to construct the solution at any time during an oscillation period. This method allows us to get the full information on the solution at any time from just storing the full 3D solutions for 2 time-steps. Table I is a summary of some characteristic results for our coupler design at the time of the workshop.

Table I: MAFIA Modeling Data

S21 / P_{TRANS}	-0.0016 dB / 99.96%
S11 / VSWR	-34.4 dB / 1.039
Bandwidth	VSWR < 1.09 for $\pm$ 10MHz
$P_{ave@surface\ (collar)}$	0.3 W/cm^2
$P_{ave@short}$	0.2 W/cm^2
$P_{ave\ in\ 6\ 1/8\ coax}$ (inner conductor)	0.06 W/cm^2
$P_{ave\ in\ 4\ in\ coax}$ (inner conductor)	0.15 W/cm^2

ADJUSTABILITY

Another feature of our coupler design is a bellows close to the tip of the center conductor. The purpose of this bellows is to add a limited adjustability to the coupler. This feature is not meant for fast online adjustments during regular operation, but to compensate for fabrication tolerances among the more than 400 cavity-coupler systems in the accelerator and for slow adjustment in situ (on the order of a few times per month.) For the time being we are numerically investigating field enhancement, rf losses and multipacting potential of these bellows. These simulations are being done with the RF_TRAK code by S. Humphries, UNM Albuquerque [6].

LOW-POWER TESTING

The simulation results obtained so far have been used to set up a low-power test of the quarter-wave-stub region. The measurements of several quarter-wave-stub geometries, including pump-port and matching collar confirmed the simulation estimates of achievable power transmission and layout of the stub region. Fig. 4 shows the experimental setup of the 6 1/8'' coaxial line with the matching collar. The view into the stub is through the pump-port. Fig. 5 gives some measurement results for different stub lengths and collar positions that lead to an optimized arrangement close to the one predicted by the simulations.

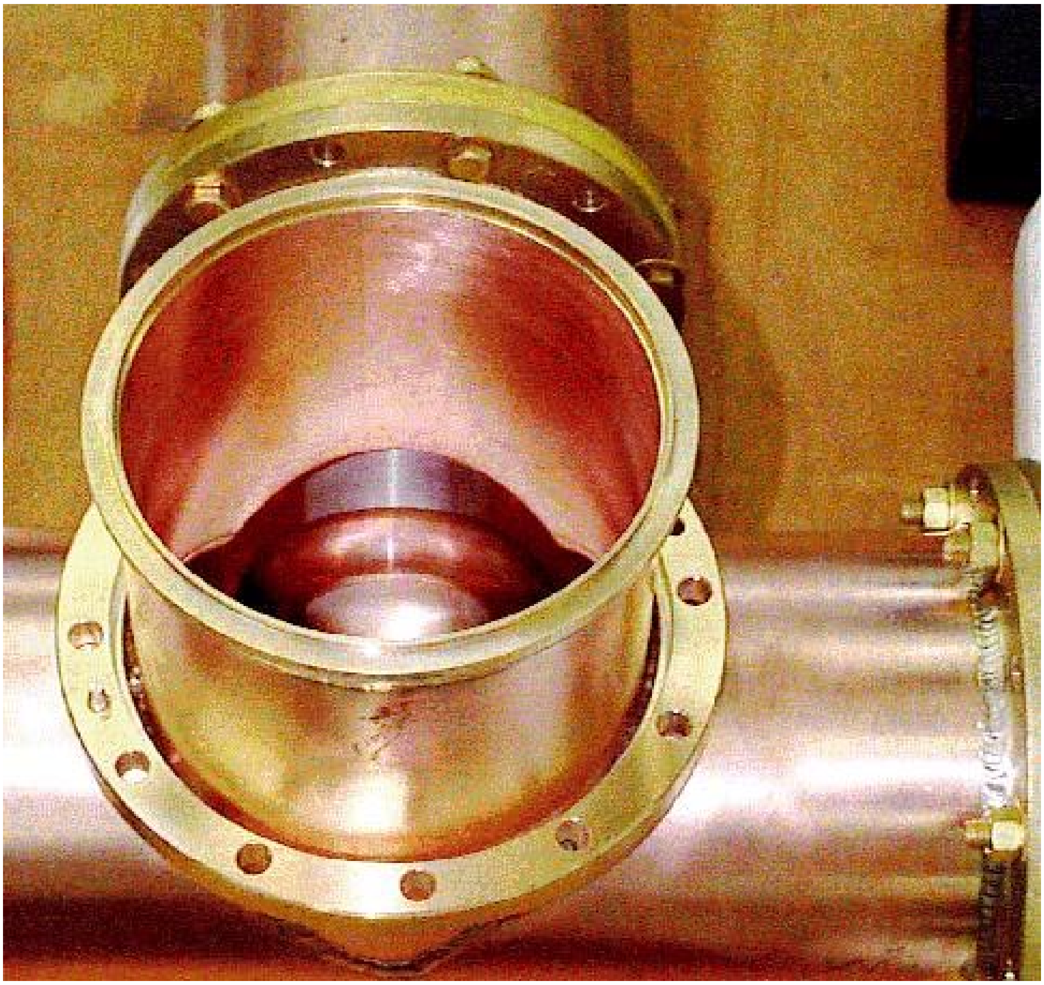

Fig. 4: Low-Power Test Setup of the Quarter-Wave-Stub and Matching Collar

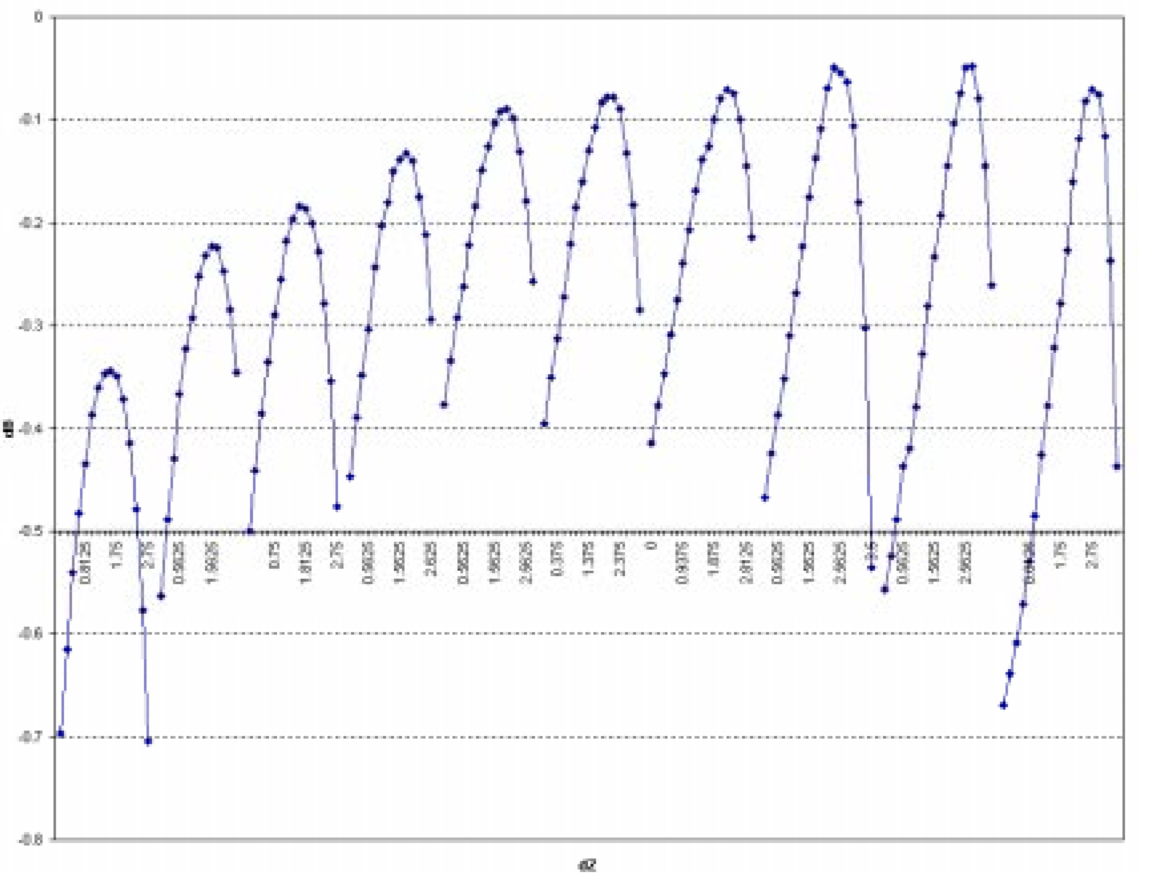

Fig. 5: Measurement Results of S21 for various Stub Lengths and Collar Positions (each curve gives S21 for a fixed collar position and varying stub positions)

CONCLUSION AND FUTURE PLANS

We have performed a first iteration of a power coupler design to provide more than 210kW of power to a superconducting cavity. The design work was performed with electromagnetic simulation software and results for single components have been confirmed in low-power lab tests. The performance of components is fulfilling the specifications. The simulations do not indicate any show-stopper in terms of expected rf performance. The coupler development is sufficiently advanced to permit pursuit of an integrated rf, mechanical and thermal design. In a second iteration we will work on an improved detailed design. We are working on an improved matching collar in the down-stream part of the coupler, close to the start of the taper. This makes room for a bellows at its old location. This bellows will alleviate possible stresses from the windows during assembly. We plan to finalize a design by the beginning of 1998. Then we will start building a coupler test stand with a single-cell cavity and four couplers, two for driving and two as a load. On this test stand, we will be able to test the couplers first up to 100kW power level on an existing klystron and later up to 1MW with a new klystron dedicated to component testing for the accelerator.

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