TESLA Input Coupler Development

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Abstract

The TeV Superconducting Linear Accelerator (TESLA) requires a RF input coupler capable of delivering 208 kW of 1.3 GHz power to a 9-cell Niobium cavity. Various electrical, mechanical, and cryogenic constraints present challenges in the design of such a coupler. Two parallel input coupler development programs are in progress at Fermilab and at DESY [1]. The Fermilab TESLA input coupler design and status is reported.

I. INTRODUCTION

The TESLA machine [2] is a next generation electron-positron collider based on two superconducting linear accelerators, each having a length of 10 km. Center of mass energies of greater than 500 GeV are planned, which will require accelerating gradients of 25 MV/m. Nine-cell superconducting Niobium cavities operating in the π-mode at 1.3 GHz will be used for acceleration. Each cryomodule will contain eight cavities with one input coupler and two higher order mode couplers per cavity. The coaxial input coupler (Fig. 1) is mounted to the beam tube adjacent to the end cell of the cavity and is capacitively coupled to the cavity. RF power for two cryomodules (16 cavities) will be provided by a single 4.5 MW klystron.

II. INPUT COUPLER DESIGN

A. Electrical

A critical component of the TESLA machine is the input coupler, which during normal operation must transport 208 kW of 1.3 GHz RF power to a 9-cell Niobium cavity. The pulse length is 1.33 ms with 0.53 ms filling time and 0.8 ms beam-on time. The repetition rate is 10 Hz, hence the average power through the coupler is nominally 2.8 kW. Additionally, it is desirable that the coupler handle power levels up to 1 MW (at reduced pulse lengths and repetition rates) so that *in situ* high peak power processing of field emission sites may be performed. At power levels of 1 MW, field strengths at the inner conductor near the cavity (outer

* Operated by Universities Research Association, Inc., under contract with the United States Department of Energy.

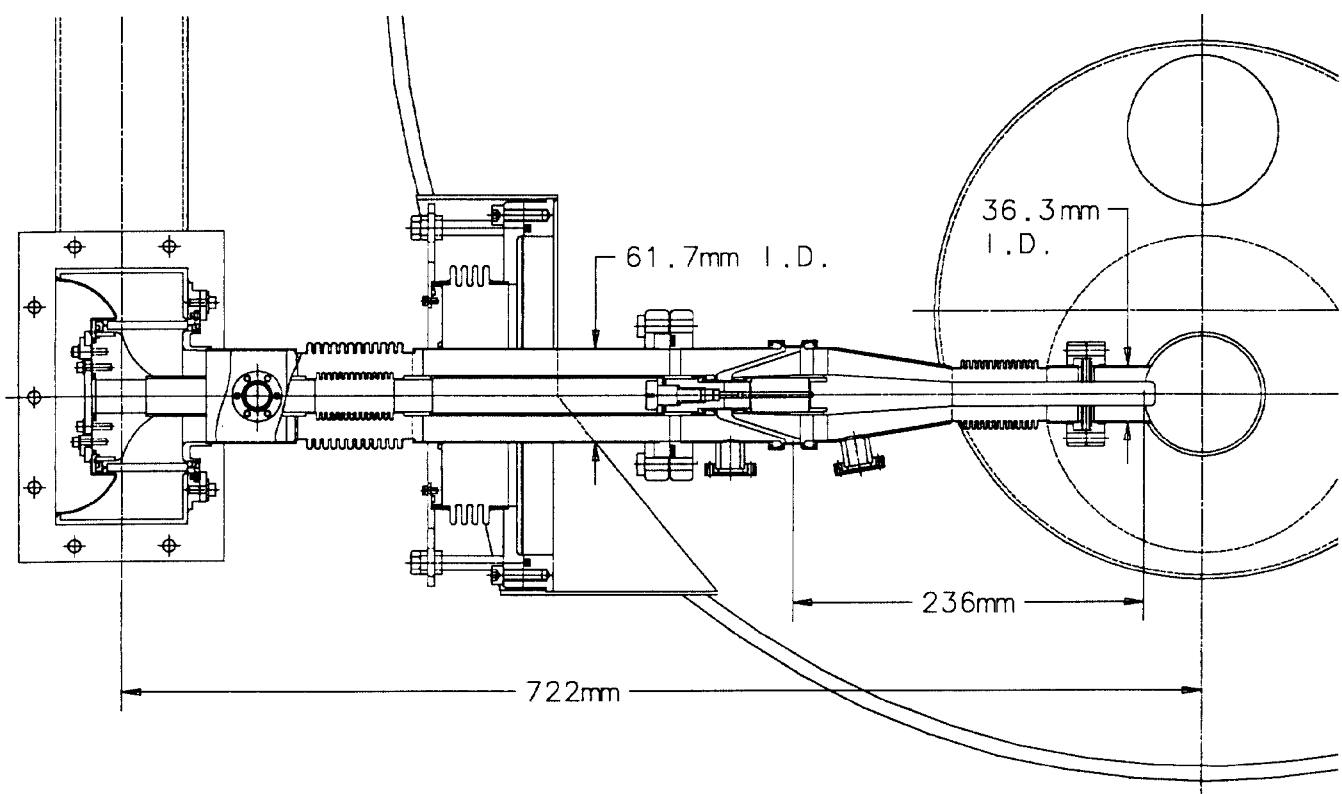

Figure 1. The Fermilab TESLA input coupler.

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conductor diameter is 36 mm) will reach 3.04 MV/m for the case of total reflection as the cavity begins to fill with energy. The external Q of the coupler is to be 3e6, adjustable over the range 1e6 to 9e6. The variable coupling is required due to variations in the cavities, couplers, and RF distribution system. The input coupler should be impedance matched for a return loss of better than 20 dB (1 % power reflection).

B. *Mechanical*

The requirement of variable coupling is met by the use of bellows on the inner and outer conductors of the coaxial input coupler as shown in Fig. 1. The inner and outer conductors move together toward or away from the beam tube by adjusting bolts outside the cryomodule. A range of motion of up to 25 mm is possible, which is adequate for the required range of external Q.

During cool down the eight cavities shrink toward one fixed point at the center of the cryomodule. The input couplers must accommodate this shrinkage, which is 15 mm worst case. Since the waveguide end of the input coupler is fixed, the coupler must be flexible so that the cavity end of the coupler can move with the cavity. This flexibility is achieved via the inner and outer conductor bellows. There is a pivot point outside of the cryomodule about which the coupler can rotate as the cavities shrink. The coupler will be mounted at room temperature so that the center conductor is off center at the beam tube. As the system shrinks during cool down, the center conductor will pivot into a position concentric to the outer conductor. Coupling adjustment will follow the cool down.

In opposition to the requirement for flexibility, there is a need to avoid mechanical vibration of the input coupler, which could lead to difficulties in controlling the amplitude and phase of the RF drive to the cavity. After coupling adjustment is complete, bolts will be tightened to secure the coupler at the cryomodule penetration.

The cold RF window must stay with the cavity once the cavity has been assembled in a clean room. Hence, the portion of the input coupler which extends out of the cryomodule must be removable. This is accomplished with an outer conductor flange joint sealed with a Helicoflex metal seal and an inner conductor joint fastened with a screw.

C. *Cryogenic*

The input coupler connects room temperature WR650 waveguide to a cavity at 1.8 K, hence minimum heat leak is necessary. This is achieved by using copper plated thin-wall stainless steel coaxial transmission line. Thermal calculations have been performed and indicate a 70 K heat load of 5.8 W and a 4 K heat load of 0.4 W.

D. *Vacuum/Cleanliness*

Two alumina ceramic RF windows will act as vacuum barriers and ensure the cleanliness of the cavity. A cylindrical window is utilized in the waveguide to coaxial transition, while a conical window is installed at the 70 K intercept in the 62 cm diameter coaxial line. Ports for pumping and instrumentation of the region between the two windows are included near the waveguide.

III. Component Development

A. *Conical Ceramic*

The conical ceramic window is the first level of protection of the cavity vacuum space. The conical shape was conceived of as a good candidate for a broad band impedance-matched window. The angle formed by the cone with respect to the axis of the coaxial line was chosen to be 18.2 degrees, which is the result of setting the angle of incidence equal to the Brewster angle for the vacuum to ceramic interface. The depth of penetration of the ceramic into both the inner and outer conductors was chosen to reduce the field strengths at the braze joints to approximately 50 % of their nominal values at the surfaces of both conductors. Two possibilities were examined for obtaining a good impedance match. One technique is to taper the ceramic thickness so that it is thinner near the inner conductor. The other method is to taper the inner or outer conductors. The tapered ceramic was rejected in order to simplify the ceramic, and because it is easier to machine metal to a new shape than to modify the ceramic. We chose to taper the inner conductor due to ease of fabrication. The thickness of the ceramic in the conical region is 3.2 mm. The Hewlett-Packard High Frequency Structure Simulator (HFSS) was used to model the ceramic. A return loss of 22 dB was achieved during simulation by iterating on the inner conductor taper.

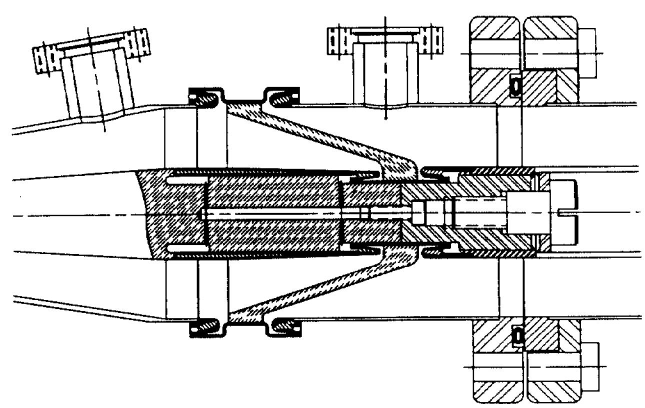

Figure 2. Detail of conical ceramic RF vacuum window.

Implementation of the design is shown in Figure 2. The ceramic is 99.5% Al_2O_3 from WESGO. The OFHC copper inner and outer conductor bands were brazed to the ceramic by Alberox. Initially, the inner conductor band contained a small plug of ceramic to prevent the band from shrinking away from the cone during the brazing cool down period. However, this plug caused cracking of the cone during brazing. The ceramic was coated with Titanium Nitride (TiN) by an evaporative process at Fermilab. The conical shape requires several evaporations with various filaments in order to achieve a relatively uniform TiN thickness. The thickness goal was 10 nm on the ceramics coated to date. The inner conductors on each side of the ceramic were attached via electron beam welding at Fermilab. The outer conductors were attached via conventional TIG welding in an Helium/Argon atmosphere.

B. Bellows

The bellows used in the prototype input coupler are off-the-shelf units that have adapters resistance welded to each end. The thin wall (0.006") bellows are hydroformed and are rated for a range of travel of 25.4 mm. Copper plating of the outer conductor bellows along with the attached stainless steel tubing is achieved by using a special apparatus consisting of a tubular electrode which is inserted into the outer conductor and is sealed at the opening of the conductor. Plating solution enters the outer conductor through holes drilled in the electrode. The other end of the outer conductor is covered with a plate that has an exit port and attached tubing to carry away the plating solution. Hence, solution is continually circulated through the outer conductor during the plating process, and the exterior of the conductor remains free of plating.

C. Doorknob Transition

The "doorknob" transition is a waveguide to coaxial transition that incorporates a cylindrical knob as the impedance transforming device. This type of transition, when properly designed, has been shown to be capable of transmitting power up to the breakdown level of the coaxial line [3]. The Fermilab doorknob transition (Fig. 3) is complicated by the decision to incorporate a cylindrical ceramic window into the transition. Not only is the transition more difficult mechanically, but also the inclusion of the window tends to reduce the bandwidth of the transition to 1-2 percent. However, this complication makes for a compact and elegant impedance transformer and vacuum barrier.

The ceramic is 99.5 % Al_2O_3 from WESGO. Fermilab fabricated the OFHC copper and 304 SS rings which were brazed to the ceramic by Alberox. The ceramic is to be TiN coated on the vacuum side (inner surface). The waveguide side of the ceramic will be exposed to > 1 Atm dry air.

The addition of a window results in the use of a two-piece doorknob. The outer piece is welded to the waveguide, whereas the inner piece is welded to the ceramic window. The ceramic and inner knob are bolted into the waveguide assembly, so the ceramic may be replaced if necessary. C-seals are used as RF joints in the bolted assembly. The shape and size of the doorknob determines the impedance characteristics of the transition. These parameters have been determined by "cut and try techniques." The HFSS program has been used to model the design and help understand the field characteristics of the transition.

IV. Conclusion

A prototype of the coaxial portion has been constructed and tested at 805 MHz at power levels up to 1.7 MW [4]. The design needs to be optimized in terms of impedance match, cost, and assembly procedures. Testing at 1.3 GHz is expected in the coming months.

A low-power prototype of the doorknob transition has been constructed and tested. Impedance matching has been achieved over a 1-2 % bandwidth. A prototype high-power transition is under development and should be ready for testing by July, 1993.

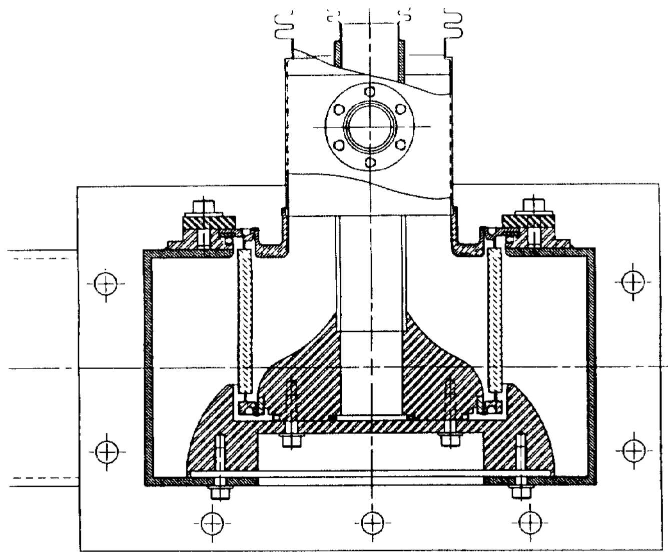

Figure 3. Detail of doorknob transition.

V. References

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