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ADJUSTABLE POWER COUPLER FOR NICA HWR CAVITIES

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Abstract

Current results on input power coupler development for Half-Wave superconducting accelerating cavity proposed for Nuclotron-based Ion Collider fAcility (NICA) collider injector upgrade are discussed. Two coupler designs are considered, first one is a low-power coupler for cavity tests and the second one is a high-power operational coupler. Both devices are of coaxial type with capacitive coupling; high-power coupler utilizes single ceramic vacuum window. NICA is designed to accelerate different types of ions. Due to the variable intensity of ion sources, beam current will vary in wide range. In order to ensure efficient acceleration, power coupler must be highly adjustable in terms of coupling coefficient. This introduces excessive mechanical stress in the ceramic RF window due to the bellows deformation. In order to mitigate this effect bellows were substituted with sliding contacts. This paper discusses new coupler design and its electrical, mechanical and thermal properties.

INTRODUCTION

In this paper we describe progress in half-wave SC cavity power coupler development. Since the last report [1] the layout of the coupler was changed. Excessive mechanical stress on the ceramic SC window in previous design could not be removed without introduction of additional suboptimal construction elements. New coupler layout is based around the idea of introduction of the EM shields to the design [2]. It allowed us to use telescopic cylinders with sliding contacts for antenna movement.

TEST COUPLER

Overview

Test coupler for the cryogenic tests was developed (Fig. 1). Since cavity operates in critical coupling mode, transmitted RF power is relatively low. This allows us to use off-the-shelf N-type connector for interfacing with the generator. In order to increase antenna immersion tuning range, welded bellows were used. Antenna is hollow with longitudinal cuts for vacuum pumping, antenna support has a truncated cone shape.

Simulation

Coupler geometry was optimized to have minimally possible reflection. Coupler reflection S_{11} is in range of $[-15, -20]\,dB$ for ceramics dielectric constant deviation $\Delta\varepsilon = \pm 0.5$ (Fig. 2).

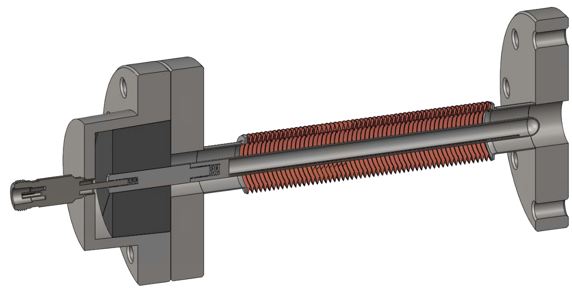

Figure 1: Test coupler model.

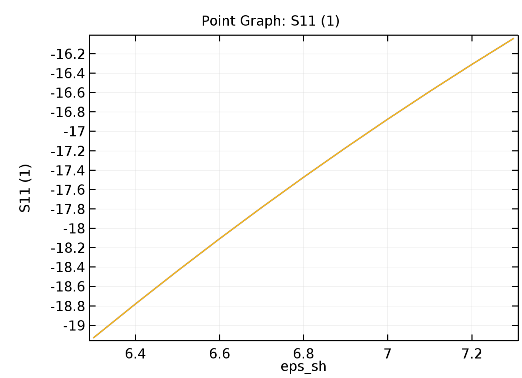

Figure 2: Test coupler reflection over ceramics dielectric coefficient.

Mechanical simulation of the test coupler were performed. Mechanical deformation of the test coupler under external force of 1 kN is shown in Fig. 3. Achieved tuning range for the test coupler is 3 cm, which is enough for the project.

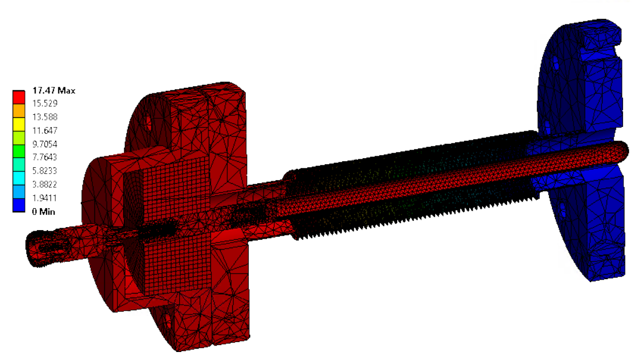

Figure 3: Test coupler deformation under 1 kN.

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POWER COUPLER

Overview

Scheme of the new power coupler layout is presented in Fig. 4.

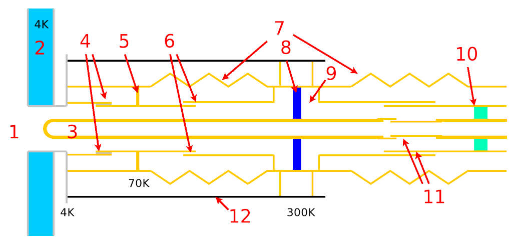


Figure 4: Power coupler scheme.

It has one ceramic RF window (8). Whole barrel window assembly (9) moves along the guide beams (12) and telescopic tubes of the coaxial transmission line. Maximum current flowing through the sliding contacts (6,11) is around $2\ {}^{A}\!/_{cm}$.

Original design of coupler with EM shields included a gap between 4 K and 70 K outer conductors (4). This may introduce additional challenges at the assembly stage [3]. As an option, gap filling with steel sleeve was considered.

Vacuum insulation is provided by bellows (7). In order to decrease force required to move the antenna, welded bellows were chosen.

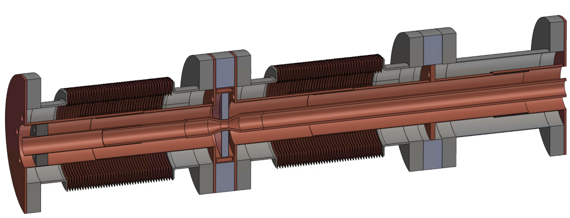
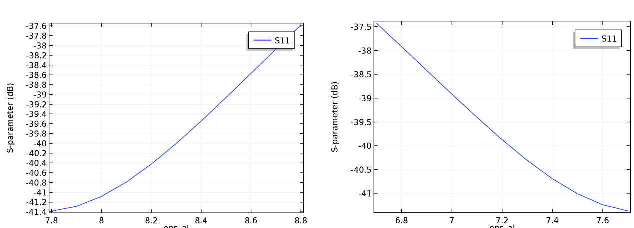


Figure 5: Power coupler model.

Power coupler model is shown in Fig. 5. Two ceramic materials were considered for the RF window: alumina and beryllium. Alumina is popular choice due to its good mechanical properties and low RF losses. Beryllium has excellent thermal conducting properties and losses even lower, but it is toxic. Coupler was matched for both ceramics (Fig. 6).

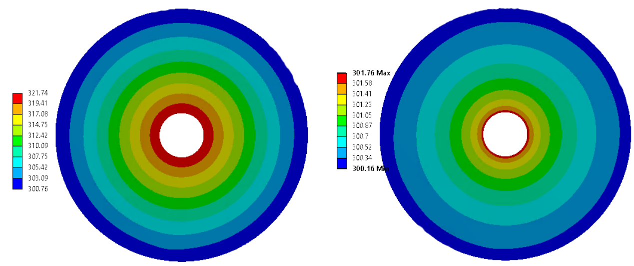


(a) Alumina (b) Beryllium

Figure 6: Power coupler reflection for alumina and beryllium RF window ceramics over dielectric constant.

Thermal Simulations

Thermal simulation of the device with two ceramic materials and two gap fillings was conducted. Temperature distributions in RF window ceramic are presented in Fig. 7. It appears that beryllium ceramics heats up only by one degree.



(a) Alumina (b) Beryllium

Figure 7: Temperature distribution on RF window ceramics.

Temperature loads on the cooling lines 4.2 K and 70 K with steel and vacuum gap filling were calculated. Calculation results are presented in Table 1. Both static and dynamic temperature loads were calculated with accounting for the heat radiation.

Table 1: Cooling Line Thermal Loads

Cooling line	Load, W steel sleeve	Load, W vacuum gap
Static load		
4.2	1.05	0.45
70	6.5	7.1
Dynamic load		
4.2	0.21	0.52
70	2.3	2.3

As expected, vacuum gap filling has lower load. Steel filling has about 30% higher thermal load on 4.2 K line, which is still acceptable. Additional experiments with the steel sleeve shape may help finding a middleground between two options, both providing low thermal load and allowing easier outer conductor centering during the assembly.

Mechanical Simulations

Mechanical simulations were conducted. External force of 3 kN allows tuning antenna immersion in desired range of 1.5 cm. Model deformation under applied force is shown in Fig. 8.

In Fig. 9 stress distribution in RF window ceramics is shown. Due to high thermal conducting coefficient, the beryllium has significantly lower stress level. Calculated safety factor is around 3 for alumina ceramics; for the beryllium ceramics it is around 6.

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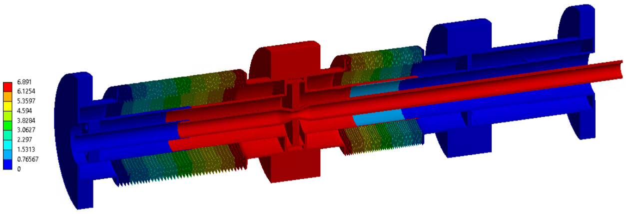
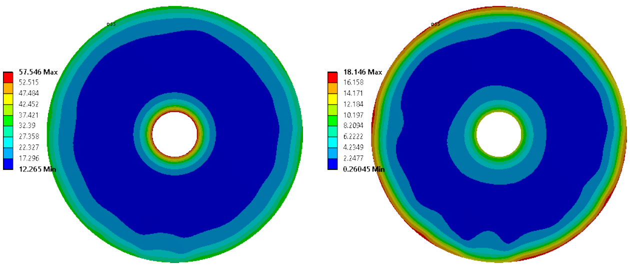


Figure 8: Power coupler deformation under 3 kN.



(a) Alumina (b) Beryllium

Figure 9: Stress in RF window ceramics.

CONCLUSION

In this paper two newly developed couplers are described. The special coulper for cavity vertical tests with wide antenna immersion range was designed and is being prepared for manufacturing. New power coupler layout was proposed. It features EM shields and sliding contacts, reducing both thermal load on the cavity and mechanical stress levels in RF window ceramics.

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