INPUT POWER COUPLER FOR NICA INJECTOR COAXIAL HALF WAVE SC CAVITY

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Abstract

Nuclotron-based Ion Collider fAcility (NICA) is being built in Dubna, Russian Federation. Usage of the accelerator superconducting HWR cavities for the injector part of the accelerator is considered. According to technical requirements power coupler is able to withstand 13 kW of RF average transmitting power. Additionally, coupling tuning in small range should be possible. In this paper results of the 325 MHz HWR power coupler R&D are presented and discussed.

DESIGN OVERVIEW

New HWR cavities are being developed for the Nuclotron-based Ion Collider fAcility (NICA) injector. These cavities comprise the $\beta = 0.21$ accelerating section [1]. Accelerator will be operating in high duty pulsed mode, however power coupler simulations were done for CW mode due to ensure some safety margin.

Model of the HWR cavity is presented in Fig. 1.

Figure 1: HWR cavity model.

The current design is based on the resutls of thermal, mechanical and electrodynamic simulations discussed below. Coupler geometry was optimised to handle necessary RF power, match the cryogenic system requirements and assure certain operation reliability. RF power is coupled to cavity via port in cavity medial plane.

It was decided to base the design of the coupler on 50 Ohm coaxial transmitting line with outer diameter of

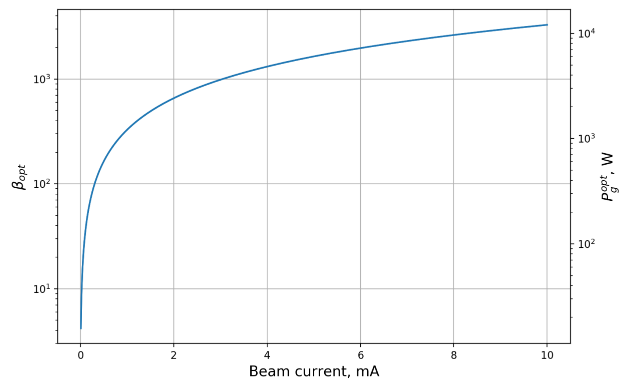

Figure 2: Power input coupling vs beam current.

47.5 mm. Conventional two RF window design was chosen. RF windows are pillbox-shaped cavities with flat ceramic disk (96 % Al_2O_3). Cold window will operate at 80 K, warm window will be at room temperatures.

For the coaxial inner conductor support rings PTFE was chosen.

According to the technical design specifications HWR power input must allow coupling tuning for operation at beam currents form 0 to 10 mA. Optimal cell coupling and RF power level for this range are shown in Fig. 2. Antenna movement in range ±7 mm will fulfill this requirement.

Bellows were introduced to the design. Cold bellows connect cavity with the cold RF window. Warm bellows mechanically decouple power coupler from the cryostat wall. Bellows metal thickness was chosen to be 0.4 mm. It is not to thin to bend significantly under its own weight yet still flexible enough to allow antenna movement in required range. To decrease temperature of the antenna and, therefore, radiation load on the 4 K line, antenna is also made out of copper.

The model of the coupler is shown in Fig. 3.

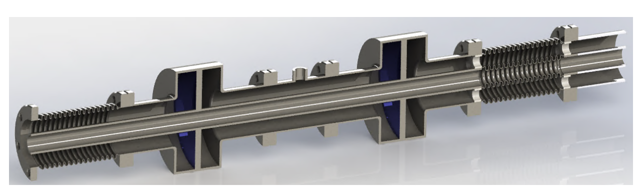

Figure 3: Two window coupler model.

HEAT LOADING

Copper coating of the conductors was considered [2, 3]. It drastically decreases the RF losses in the metal but also

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increases the thermal conductivity. Effective thermal conductivity of the layered material was estimated using this equation [4]:

$$k_{eff} = \frac{t_a}{(t_a + t_b)} k_a + \frac{t_b}{(t_a + t_b)} k_b,$$

where k_a and k_b are the thermal conductivities of the materials and t_a and t_b are their thicknesses.

Calculated heat loads on the cooling contours are presented in Table 1. Radiation calculation were done using the emissivity factor of 0.8 which corresponds to the highly oxidised copper so this estimation is very conservative.

Table 1: Heat loads

Type	Value, W
2 K static w/o copper	0.1
2 K static w copper	0.25
2 K dynamic w/o radiation, w/o copper	6.7
2 K dynamic w/o radiation, w copper	0.95
2 K dynamic w radiation, w/o copper	5.71
2 K dynamic w radiation, w copper	0.97
80 K static w/o copper	7.7
80 K static w copper	7.97
80 K dynamic w/o copper	54.31
80 K dynamic w copper	23.6

Total heat load on the 2 K cooling line is 1.22 W with copper coating of the conductors and 5.81 K without it. It is clear that copper coating of the conductor surfaces is necessary. Note that radiation actually cools down steel bellows because they are hotter than the inner conductor.

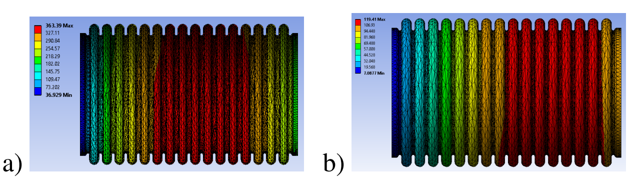

Figure 4: Temperature of the bellows without (a) and with (b) copper coating.

Fig. 4 shows the temperature of the cold bellows with and without copper coating. Without coating temperature of the bellows gets as high as 360 K which is unacceptable.

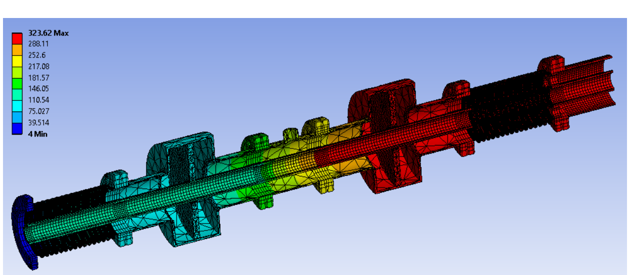

Figure 5: Temperature of the coupler in operation.

In Fig. 5 temperature of the coupler with copper coating is presented.

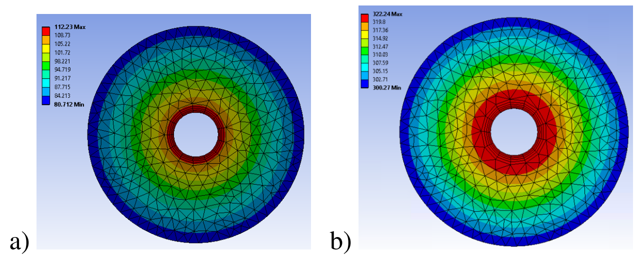

Figure 6: Temperature of the cold (a) and warm (b) windows.

Cold and warm ceramic temperature distributions are shown in Fig. 6.

MECHANICAL DEFORMATIONS

Mechanical stress on ceramic disk caused by thermal deformations and force applied by coupling adjustment actuator were estimated.

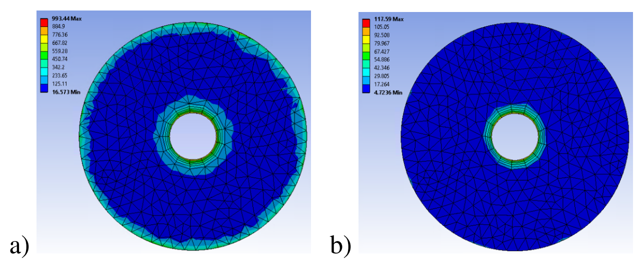

Figure 7: Mechanical stress in the cold (a) and warm (b) windows.

In Fig. 7 mechanical stress in RF window ceramics is presented. The maximum stress to 6 mm thick ceramic disk of the warm RF window is about 120 MPa is about three times lower than ordinary Alumina strength. Cold window however appears to exceed the maximal stress. Therefore it is necessary to include a stress relief mechanism to the cold RF window. Spring-loaded double wall seems to be a resonable solution to the problem. Development of such connection is now in progress.

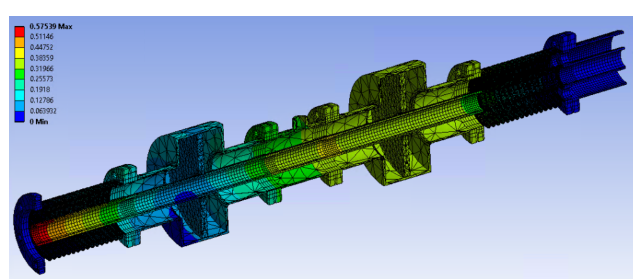

Figure 8: Deformation of the coupler.

Total deformation of the coupler is shown in Fig. 8. It is clear that gravitational pull does not bend bellows significantly, so it is not necessary to increase their thickness.

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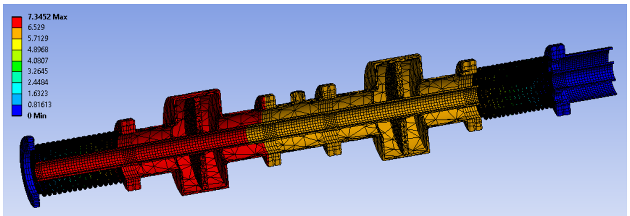

Figure 9: Deformation of the coupler under 7 kN load.

a) b)

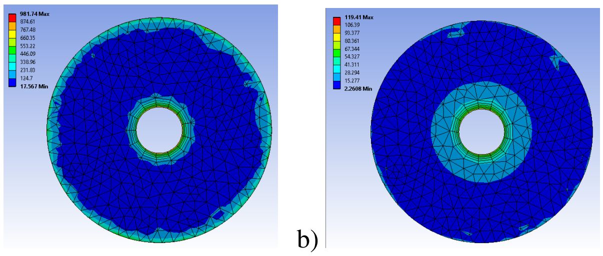

Figure 10: Mechanical stress in the cold (a) and warm (b) windows under in an additional stress, caused by the bellows deformation.

In order to simulate a movement of the coupler, force was applied to the RF windows. It requires pulling coupler with the force of 7 kN in order to move it ±7 mm. Full deformation of the coupler is shown in Fig. 9 Mechanical stress in RF window ceramics under this additional stress is presented in Fig. 10.

Warm window streess in this mode of operation is also well below the dangerous level for ceramics proposed.

CONCLUSION

Steps of designing initial model of the NICA low-beta power input were discussed in this paper.

Thermal and mechanical calculations were done for the coupler. Minimum heat load on the 2 K cooling circuit of 1.22 W was achieved with the use of a copper coating of the coupler conductors.

Mechanical calculations showed that bellows do not bend under their own weight. Coupler posses an ability to move in a required tuning range. Stress calculations showed that the cold window experience high stress and needs to be reduced by introduction of the spring-loaded connection. Force, required to move antenna in requested range is 7 kN.

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REFERENCES

[1] M. Gusarova *et al.*, "Selection of the Type of Accelerating Structures for the Second Group of Cavity SC Linac Nuclotron-NICA," in *Proc. of International Conference on RF Superconductivity (SRF'17), Lanzhou, China, July 17-21, 2017*, (Lanzhou, China), ser. International Conference on RF Superconductivity, https://doi.org/10.18429/JACoW-SRF2017-MOPB034, Geneva, Switzerland: JACoW, Jan. 2018, pp. 125–127, ISBN: 978-3-95450-191-5. DOI: https://doi.org/10.18429/JACoW-SRF2017-MOPB034. http://jacow.org/srf2017/papers/mopb034.pdf

[2] I. Irfan, S. F. Chapman, W. Kaabi, M. Krishnan, and K. M. Velas, "Energetic Copper Coating on Stainless Steel Power Couplers for SRF Application," in *Proc. of International Conference on RF Superconductivity (SRF2015), Whistler, BC, Canada, Sept. 13-18, 2015*, (Whistler, BC, Canada), R. E. L. (V. B. C. J. T. (V. B. C. V. R. S. (D. Germany), Ed., ser. International Conference on RF Superconductivity, JACoW, Geneva, Switzerland: JACoW, Dec. 2015, pp. 1330–1334, ISBN: 978-3-95450-178-6. DOI: 10.18429/JACoW-SRF2015-THPB083. http://srf2015.vrws.de/papers/thpb083.pdf

[3] S. Sierra, G. Garcin, M. Knaak, C. Lievin, M. Pekeler, and G. Vignette, "Lesson Learned on the Manufacturing of Fundamental Power Couplers for the European XFEL Accelerator," in *Proc. of International Conference on RF Superconductivity (SRF2015), Whistler, BC, Canada, Sept. 13-18, 2015*, (Whistler, BC, Canada), R. E. L. (V. B. C. J. T. (V. B. C. V. R. S. (D. Germany), Ed., ser. International Conference on RF Superconductivity, JACoW, Geneva, Switzerland: JACoW, Dec. 2015, pp. 1370–1372, ISBN: 978-3-95450-178-6. DOI: 10.18429/JACoW-SRF2015-THPB096. http://srf2015.vrws.de/papers/thpb096.pdf

[4] user7938238, *Thermal conductivity of a layered composite*, May 2018. https://engineering.stackexchange.com/a/21965