RF INPUT POWER COUPLERS FOR HIGH CURRENT SRF APPLICATIONS

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Abstract

High current SRF technology is being explored in present day accelerator science. The bERLinPro project is presently being built at HZB to address the challenges involved in high current SRF machines with the goal of generating and accelerating a 100 mA electron beam to 50 MeV in continuous wave (cw) mode at 1.3 GHz. One of the main challenges in this project is that of handling the high input RF power required for the photo-injector as well as booster cavities where there is no energy recovery process. A high power co-axial input power coupler is being developed to be used for the photo-injector and booster cavities at the nominal beam current. The coupler is based on the KEK–cERL design and has been modified to minimise the penetration of the coupler tip in the beam pipe without compromising on beam-power coupling (Q_{ext} ~10^5). Herein we report on the RF design of the high power (115 kW per coupler, dual couplers per cavity) bERLinPro (BP) coupler along with initial results on thermal calculations. We summarise the RF conditioning of the TTF-III couplers (modified for cw operation) performed in the past at BESSY/HZB. A similar conditioning is envisaged in the near future for the low current SRF photo-injector and the bERLinPro main linac cryomodule.

INTRODUCTION

Super conducting (SC) energy recovery linac (ERL) machines are being explored in various laboratories not only to be used as a particle collider but also as a potential candidate for the next generation light sources. A brief listing of the current SRF ERL projects around the world is presented in [1]. The bERLinPro [2] project is envisaged to circulate a 100 mA, 50 MeV electron beam accelerating through SC cavities at 1.3 GHz. One of the main aspects of the bERLinPro project is to circulate the high current beam whilst preserving the beam quality. Another important feature is handling of the high cw RF power of 230 kW per cavity in the photo-injector as well as booster cavities where there is no energy recovery process. In the initial stages, the photo-injector and booster cavities will be tested at a low current of 5 µA and 4 mA. Hence at these stages the TTF-III couplers modified for cw operation [3] at 10 kW (low power) will be utilised for the injector cavity. Whereas for the nominal final 100 mA current operation a high power coupler, referred to as bERLinPro (BP) coupler is being developed [4-5]. The RF design of the BP coupler is based on the cERL-KEK [6-7] coupler design. The RF conditioning of the cw TTF-III couplers is envisaged at HZB for the SRF photo-injector in the near future. As the similar test has been performed at BESSY/HZB in the past, we briefly mention those results in the next section. The following section describes the high power BP coupler design along with the initial thermal calculations. We summarise the present results and future plans in the final section.

LOW POWER COUPLER

The original RF parameters of the TTF III coupler for XFEL are: peak input power 250 kW, pulse length 1.3 ms and repetition rate 10 Hz [8]. This implies the average power ~3.2 kW. In travelling wave (TW) operation at room temperature the coupler's designed temperature rise is about 25-30 K/kW. In order to test the TTF III couplers at cw operation, RF conditioning tests were performed in collaboration with DESY, Cornell, HZB and HZDR at Rossendorf (at room temperature) and BESSY/HZB (room and SC temperatures) [3]. A detailed design of the TTF III input power coupler and test stand are presented in Fig. 1.

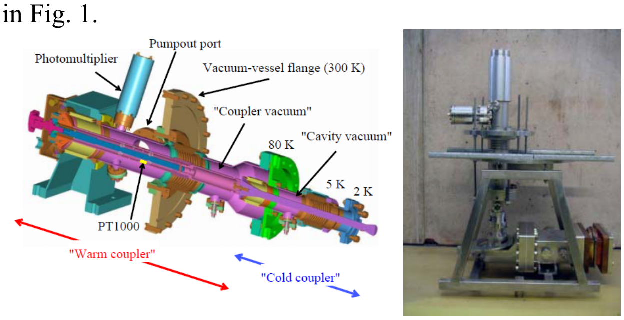

Figure 1: The TTF III coupler (left) and test stand (right).

The experimental set up at BESSY/HZB's HoBiCaT test facility and various tests performed are presented in [3]. In order to test the coupler at a higher average cw power, a modification was done to the inner conductor to improve the power dissipation. The TTF III coupler relies only on conduction cooling; hence its power handling capability is limited to 5 kW. To improve the cooling of the inner conductor, a tube was introduced to allow a room temperature air flow at 20 litre/min. This increases the power handling capability up to 10 kW. The coupler was tested at 4 kW power at room temperature. The cold test was limited to 2 kW power due to severe outgassing leading to arcing in the RF load (which was placed in the vacuum). In both the warm and cold tests the temperature rise was about 29 K/kW [3]. The bERlinPro photo-injector (initial stage 4 mA) and main linac cavities need 10 kW power/cavity dependent on the actual level of microphonics. Hence dual TTF III couplers per cavity

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with modified inner conductor cooling will be utilised. The RF conditioning of the coupler using the test stand in Fig. 1 (right) will commence shortly at HZB.

HIGH POWER COUPLER

BP Coupler Design

The baseline design of the high power BP coupler strongly relies on the cERL-KEK [6-7] design. Unlike the TTF III coupler this is a fixed coupler and hence it puts additional constraint on the design and simulations in order to meet the desired coupling to the cavity. The RF design details of the BP coupler are presented in [4]. Similarities between the cERL and BP coupler are the designs of: 5K-80K heat intercepts, RF window and choke geometry near the window. The changes made to the coupler to meet the bERLinPro requirements are- the addition of the golf-tee tip of the inner conductor, smooth inner conductor geometry, no bellow in the inner conductor warm part, door knob geometry, water cooling for both, the inner and air-side outer conductor. The inner conductor tip was modified for enhancing the beam-power coupling without deep insertion of the tip into the beam tube. For the booster cavities, a Q_{ext} = 10^5 is required and this is achieved with only a 3 mm insertion into the 88 mm diameter beam pipe. -In addition, removing the Teflon disc (used as a back-up against cracking of the ceramic window in the original KEK design) from the warm part of the coupler resulted in the smoother geometry of the inner conductor. The inner conductor bellow (in the warm part) minimises the pressure exerted on the RF window due to the thermal expansion of the inner conductor. However, the bellow is also expected to heat significantly. If the inner conductor is efficiently cooled then it reduces the chances of its expansion. Hence, if the thermal expansion is well controlled, removing the bellow should not exert pressure on the RF window. A detailed geometry of the BP coupler along with the booster cavity, displaying several details such as the golf-tee tip, heat intercepts, etc. is presented in Fig. 2.

Thermal Calculations

The inner conductor is going to be fabricated of copper (Cu), however the outer conductor will be stainless steel (SS) with the inner coating of copper (at least 10 µm). We utilise commercially available software ANSYS WB [9] for calculating the RF and thermal properties of the coupler. For the simplification of the thermal calculations, the thermal conductivity of the SS coated with Cu is approximated as a weighted average with respect to their thicknesses ($\lambda = (\lambda_{cu} d_{cu} + \lambda_{ss} d_{ss})/(d_{cu}+d_{ss})$) [10]. Whereas for the calculations of the power loss on the outer conductor only electrical conductivity of Cu is taken into account as the skin depth at 1.3 GHz is ~1.8 µm and is well within the Cu thickness. The non-linear behaviours of the materials at cryogenic temperatures are also taken into account. The SS-Cu weighted thermal conductivities for different thicknesses are presented in Fig. 3. Two main cases can be studied in this problem, beam off (full reflection) and beam on (no reflection) cases at maximum input power of 115 kW. In the first case of full reflection (S_{11}= 0 dB), power losses on the surfaces are maximum and this is the worst case scenario.

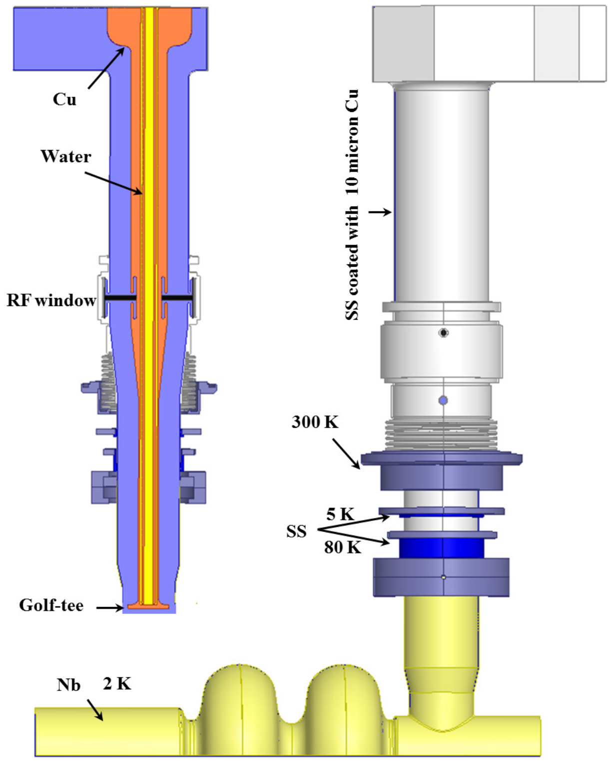

Figure 2: BP coupler design.

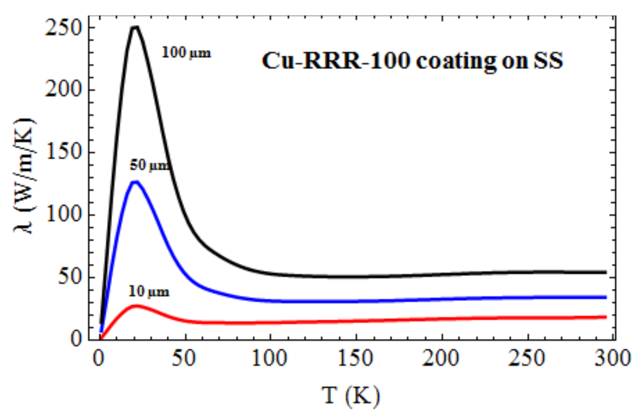

Figure 3: Thermal conductivity.

In the original KEK coupler design only the inner conductor was water cooled; in this case, the initial simulations indicated excessive temperature rise on the outer conductor. For the sake of calculations we implemented forced convection on the outer surface of the outer conductor with a coefficient of 300 W/m^2/K. In reality, uniform cooling through water channels will be provided. The preliminary simulation result in case of full reflection is illustrated in Fig. 4 indicating a temperature rise in the vicinity of the RF window of ~180 K (initial temp. = 300 K). In practice this temperature rise can further be minimised by increasing the water flow of the outer conductor cooling channel. The cold parts of the coupler do not seem to experience excessive temperatures. Table 1 shows power loss on the coupler and booster surfaces. It is evident from the power loss on the outer conductor surface (Fig. 4 and Table 1) that it is necessary to incorporate water cooling not only in the coax region of the outer conductor but also in the doorknob waveguide section. The heat absorbed in the cavity (Nb, 2K), and 5K - 80K intercepts are presented in Table 2.

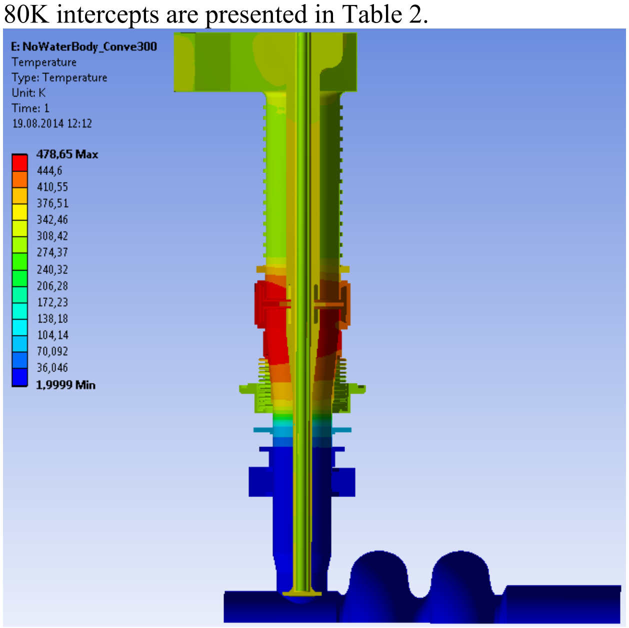

Figure 4: Thermal simulation: in case of full reflection.

Table 1: Surface Losses in BP Coupler

Input Power 115 kW, S_{11}=0 dB, Full reflection		
Surface loss (W)		
1	Inner conductor (Cu)	430.4
2	Outer conductor (SS-Cu)	260.4
3	Cavity (Nb)	8.1
Volume loss (W)		
4	RF window	61.9

Table 2: Heat Absorbed in Temperature Intercepts

#	Temp intercept	No heat load	Heat load
	K	W	W
1	2	1.38×10^{-2}	8.2
2	5	4.5	7.0
3	80	1.57	19.0

The heat absorbed in the cavity might seem to be high. However, as mentioned it is the full input power in the absence of beam. In reality, in the absence of beam, the cavity will be operated only at one fourth of the full power; hence the heat absorbed will also be reduced.

In the second case when the beam is on, almost all the power is taken by the beam. This is the operating scenario in general and will have minimum losses on the surfaces. To simulate this case using the available software is a tricky problem (because we cannot incorporate beam loading). We cut the warm section of the coupler in two parts, from door knob to the RF window and window to the bellows. The input power in these cases is 115 kW. As these sections are coaxial lines, nearly all the power is transmitted; the reflection in these cases is S_{11}~-20 dB.

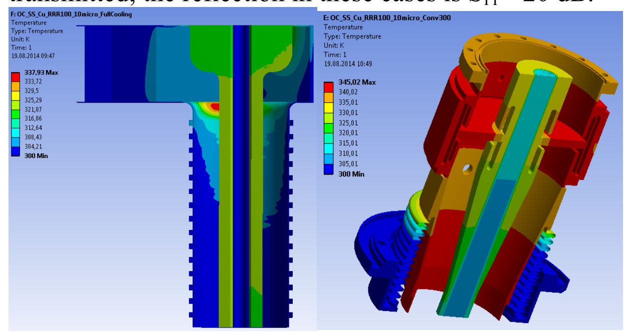

Figure 5: Thermal simulation: in case of no reflection.

This indeed depicts the scenario when the beam is on in a realistic case. The maximum temperature rise in this case is ~45 K. For the RF conditioning of the BP coupler, a test box has been designed [4] and it will be operated in TW condition so that two couplers can be tested at once.

FINAL REMARKS

The RF conditioning of the cw TTF-III coupler is due shortly. The water cooling channel design for the outer conductor is underway to finalising and optimising the BP coupler design. The SC coaxial power couplers being developed for the bERLinPro project can potentially be utilised for the future projects such as BESSY VSR [11] at HZB.

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REFERENCES

[1] J. Knobloch, LINAC'10, 2010.
[2] J. Knobloch, ICFA Beam Dynamics Newsletter, No. 58, p118, 2012.
[3] J. Knobloch *et al.*, PAC'05, 2005.
[4] V. F. Khan *et al.*, WEPRI006, IPAC'14, 2014.
[5] A. Neumann *et al.*, WEPRI007, IPAC'14, 2014.
[6] E. Kako *et al.*, THOBAU02, SRF'09, 2009.
[7] E. Kako *et al.*, WEPPC012, IPAC'13, 2013.
[8] M. Dohlus *et al.*, MOP67, LINAC'2004, 2004.
[9] www.ansys.com
[10] R. Bonomi *et al.*, CERN-ACC-Note-2014-0020-(2013).
[11] G. Wustefeld *et al.*, THPC014, IPAC'11, 2011.

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