120 kW RF POWER INPUT COUPLERS FOR bERLinPro*

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Abstract

The 50 MeV, 100 mA energy-recovery-linac (ERL) demonstration facility bERLinPro is currently undergoing construction at HZB. The high power injection system, that will deliver a beam at 6 MeV, is split into a 1.4 cell SRF photo injector and three Cornell-style 2-cell boosters. The injector and two of the booster cavities will provide about 2 MeV each and must handle up to 220 kW of beam loading. New, cERL-based 115 kW TW high power couplers needed for the cavities' twin coupler system have begun manufacture. The design, optimization and manufacturing considerations of these couplers are presented.

INTRODUCTION

The bERLinPro project [1] has a 1.4 cell photo injector that provides an average beam current of 100 mA at 2.3MeV [2]. Before passing into the energy recovery linac, the beam passes through three 2-cell Cornell type superconducting booster cavities [3]. The first cavity operates in a zero crossing regime to provide chirping of the beam. The other two cavities provide 220 kW of power to accelerate the beam to 6.5 MeV.

The baseline of the design was originally based on the compact-ERL (cERL) for KEK. However, the tip was modified to increase the coupling without imparting a beam kick caused by the coupler penetrating into the beam pipe. Additional cooling was also included because of the higher power demand. This design was then modified further to accommodate restrictions placed upon the design from a construction point of view. This paper will discuss the requirements of bERLinPro, the changes to the design to accommodate ongoing work and the current status of various parts of the coupler. To aid with manufacture the design was split into two parts, the warm part consisting of the transition from wave guide to coaxial line, and the cold part consisting of the ceramic vacuum break and coaxial to beam pipe transition. The 'cold part' of the coupler was successfully put out to tender at the end of 2016. The 'warm part' was put successfully put out to tender at the start of 2017.

COUPLER REQUIREMENTS

The 1.3 GHz high power bERLinPro couplers are expected to deliver 220 kW in parallel to each booster cavity. Table 1 lists the main coupler requirements for bERLinPro, the current design fulfils all parameters. This version was altered from previously presented designs to fit with the requirements of the cryo-module. This primarily consisted of increasing the length of the warm part to reduce the need for a complex multi-step transition around the port of the cryo-module. This also allowed the wave-guide paths to be simplified. The area around the doorknob was also modified to provide a more uniform distribution of peak field to avoid arcing. The electromagnetic model was altered to accommodate the need for a longer warm part to clear the outer radius of the cryo-module, and the cooling pipes for the ceramic window were altered to allow for the couplers to be independent of each other.

Table 1: Parameters of the 1.3 Ghz bERLinPro Couplers

Parameter	Value
Central Frequency	1.3 GHz
Bandwidth	± 1 MHz
Max RF power supplied by the amplifier	120 kW
Mean power	110 kW
Number of ceramic windows	1
Q_{loaded}	1.05×10^5
Total Heat Leak to 2 K	<1 W
Total Heat Leak to 5 K	<5 W
Total Heat Leak to 80 K	<80 W

A cut away of the current complete coupler design is shown in Fig. 1.

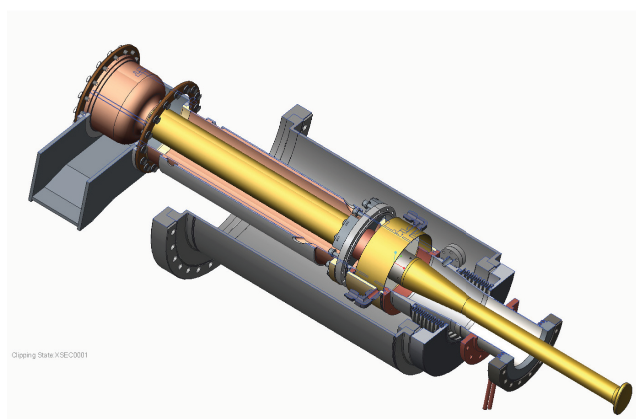

Figure 1: Cut away of the complete coupler.

RF DESIGN

The requirement of Q_{ext} for bERLinPro means a higher coupling is needed compared to the c-ERL. Unfortunately the the simplest method of increasing the penetration of the coupler is infeasible due to the increased transverse electric field and potential for high coupler kicks. To avoid this the tip was modified to a golf-tee shape that increases coupling without the need to insert the tip excessively into the beam tube [4].

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The magnetic fields of the coupler are shown in Fig. 2, and the electric fields are shown in Fig. 3. The peak electric field is mostly located in the warm part around the transition to coaxial line. The peak field for 120 kW traveling wave is 1.22 MV/m, which is within the acceptable limit of 3 MV/m for dry air to prevent arcing. These fields were calculated using the commercial available software HFSS [5]. The peak magnetic field is primarily located around the doorknob. This area will have dedicated water cooling.

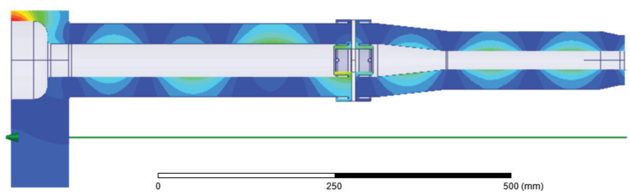

Figure 2: Magnetic field distribution.

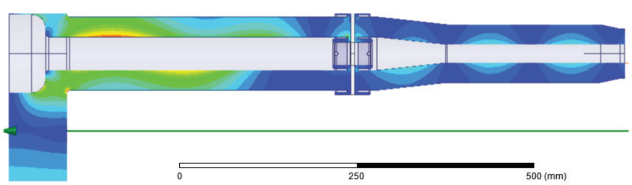

Figure 3: Electric field distribution.

Figure 4 shows the S-parameters of the coupler. The coupler has been optimised to have a good broad transition at 1.3 GHz with a S_{11} of −31 dB and a 3dB bandwidth of 3 MHz. Due to the design of the cold part of the coupler being frozen and put on order before the full design was finalized, the bandwidth optimisation had to be done via modifying the warm part. Therefore the main parameter for coupling optimisation was the outer radius around doorknob.

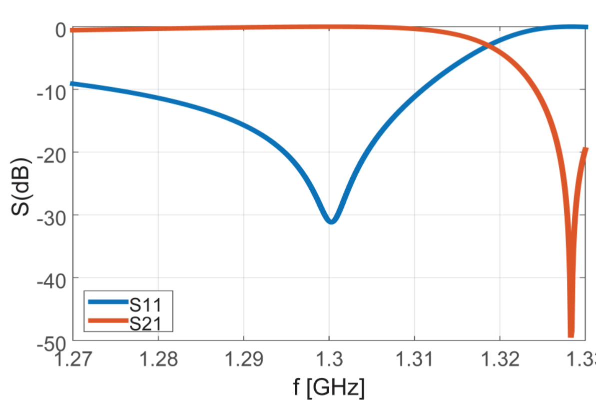

Figure 4: S paramaters of the coupler.

THERMAL CONSIDERATIONS

Thermal simulations were carried out on the design to ensure that the heat load to the cavity was kept to a minimum. Three scenarios were examined to cover the various modes of operation.

- Full power travelling wave.
- Quarter power standing wave, no beam, full reflection.
- Full power standing wave, no beam.

During these studies cooling was applied to the places of greatest expected heating, derived from initial RF studies. A RRR value of 10 was chosen for surface losses. The thermal loads the the various heat intercepts are shown in Table 2.

Table 2: Thermal Study bERLinPro Couplers

Intercept	Static (W)	Dynamic (W)	Total (W)
2 K	0.09	0.165	0.255
5 K	1.634	0.863	2.624
80 K	4.363	12.512	14.023

The expected temperature of the coupler during full power is shown in Fig. 5 and is within reasonable limits. The peak temperature is 60°C which is seen on the ceramic. The majority of the non cold coupler is maintained at around room 30°C.

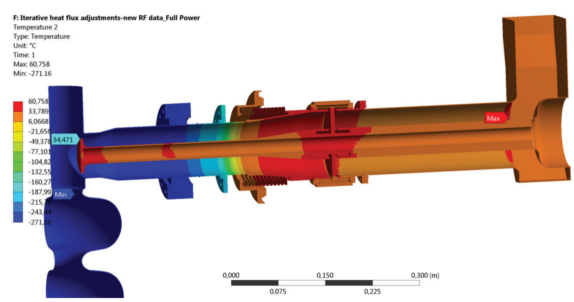

Figure 5: Thermal distribution in the coupler.

MECHANICAL DESIGN CONSIDERATIONS

Due to the high power nature of the coupler the thermal considerations are important. As other couplers have had heating issues arising from the complicated nature of copper coated bellows, the decision was taken early on to have no bellows facing the internal RF surface. This removes much of the risk of using copper coating. However it also decreases the thermal path length between 300 K and the 5 K intercept. The design decision was taken to integrate the 5 K intercept into the primary flange of the coupler. This allows the 80 K intercept a greater freedom of position. Figure 6 shows the location of the water cooling inputs for the warm part. Figure 7 shows the locations of the external bellows as well as the positions of the heat intercepts on the cold part. The design contains multiple separate water cooling points to accommodate for the heat load.

Internal water cooling is present in the coaxial parts that provides cooling for the entire length of the inner conductor. Both the warm parts and the cold parts inner conductors have direct water cooling. The doorknob, as a likely location of heating due to the high magnetic field, has direct water

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cooling. To ensure that the heat load to the 80 K, 5 K and 2 K intercepts is minimised, the structure between the ceramic window and the 5 K flange consists of a thin walled stainless steel tube that has been coper coated with 15 μm of copper. This thickness of copper was chosen as a compromise between increased thermal transport due to the increased copper thickness and potential variation in copper thickness leading to poisoning via the nickel strike.

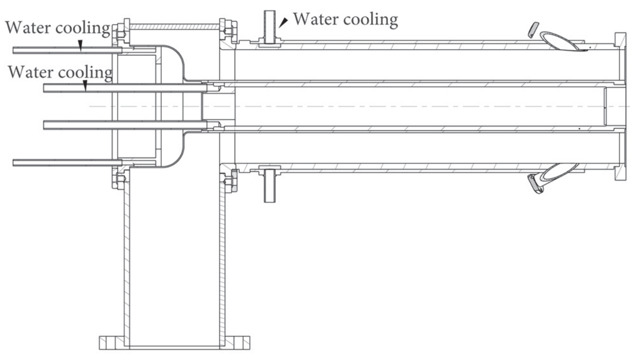

Figure 6: Cooling locations on the warm part of the coupler.

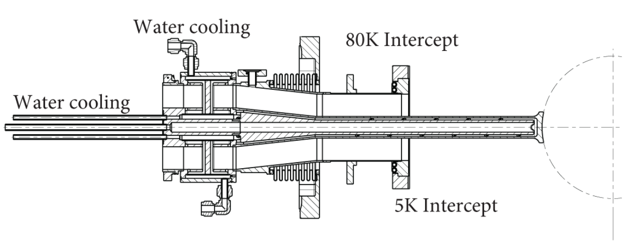

Figure 7: Cooling locations on the cold part of the coupler.

DESIGN ALTERATIONS DUE TO BOOSTERS

The three complete booster cavities with attached helium jackets attached were delivered to HZB some time ago. The coupler ports on these cavities were measured by CMM machine to determine their variation from the nominal design. These variations were then used to calculate the expected change in Q_{ext}. The primary impact on the Q_{ext} was the distance between the beam axis and the face of the coupler flange. These variations are summarised in table 3, cavity B4 is the spare.

The other dimensions were well within tolerance and had negligible variation. The variation in absolute Q_{ext}expected by a miss alignment of one or both in the position of the coupler is shown in Fig. 8. Even for a significant variation in position of 2 mm only a 20% variation in Q_{ext} is expected however this does not account for coupler kicks, although they are expected to be low [6]. Another consideration that is being examined is the additional thermal stress applied to the coupler due to the power miss match. With the ability to compensate for manufacturing errors on this order of magnitudes it is expected that we will be easily able to achieved

Table 3: Variation of the bERLinPro booster cavity ports

Cavity designation	Deviation (mm)	Uncorrected Q
B1 - left	−0.85	9.73×10^4
B1 - right	−0.2	1.09×10^5
B2 - left	−0.67	1.00×10^5
B2 - right	−0.21	1.08×10^5
B3 - left	0.16	1.15×10^5
B3 - right	−0.89	9.66×10^4
B4 - left	−1.39	8.91×10^4
B4 - right	−0.9	9.65×10^4

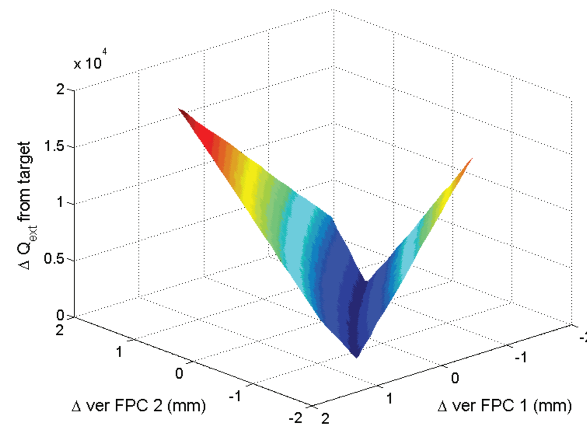

Figure 8: Variation in Q_{ext} due to coupler variation.

the desired Q_{ext}. It was decided that the outer conductor of all the the coupler would be shortened to accommodate the single increased port length of Booster B3. This will allow the desired Q_{ext} to be maintained even if all couplers have a reduced penetration depth due to all being shorter than desired but within variation. The decision was taken to use varying copper gasket thickness's to compensate for coupler and port variation as this will allow for any variation in the final delivered product.

CONCLUSION

The RF design for the bERLinPro high power coupler has been finished and the coupler meets all of the design requirements. Both the cold and warm parts are currently undergoing manufacture with delivery to be completed before the end of 2017. The test box is currently under going mechanical design.

ACKNOWLEDGEMENTS

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