DESIGN OF THE HIGH POWER 1.5GHz INPUT COUPLERS FOR BESSY VSR

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Abstract

The Variable pulse length Storage Ring (BESSY VSR) upgrade to BESSY II at Helmholtz-Zentrum Berlin (HZB) requires an upgrade on the RF systems in the form of high-voltage longitudinally focusing super conducting RF cavities of 1.5 GHz and 1.75 GHz. Coaxial RF power couplers capable of handling 13 kW peak power at standing wave operation, are required to provide an average power of 1.5 kW for both the 1.5 GHz and 1.75 GHz cavities. The coupler is intended to provide variable coupling with a range of Q_{ext} from 6×10^6 to 6×10^7 providing flexibility to adjust to operating conditions of BESSY VSR. Here we present the RF design of the high-power 1.5 GHz coaxial coupler for BESSY VSR.

INTRODUCTION

BESSY VSR is an upgrade to BESSY II at the Helmholtz Zentrum Berlin, with new superconducting RF cavities, 1.5 GHz and 1.75 GHz, which provide simultaneous operation of long and short pulses [1]. Due to the zero-crossing operation mode, the given detuning allows for operation of the cavity with close to zero beam loading meaning the coupling and Q_{loaded} are only dictated by the expected average and peak detuning [2]. Therefore, the SRF cavities have to be detuned within tight margins to ensure stable operation and low power consumption at the loaded Q of 5×10^7 [3]. This paper presents the design for the high power couplers for the 1.5 GHz cavities [4]. This coupler is required to provide variable coupling in the range of 6×10^6 to 6×10^7 to allow for optimal coupling based on the operating conditions of the machine. Additionally this allow for safe parking of the cavities when they are not in use.

Table 1: Parameters of the 1.5 GHz BESSY VSR Coupler

Parameter	Value
Central Frequency	1.5 GHz
Bandwidth	0.01 GHz
Peak power in coupler	13 kW
Average power	1.5 kW
Q_{ext} range	6×10^6 to 6×10^7
Q_{loaded}	5×10^7

The coupler has a power overhead of 16 kW, the main fraction of which is taken by any deviation of the estimated reactive beam-loading compensation from the real beam current and cavity voltage. This 16 kW accounts for 13 kW peak power in the coupler and an additional 3 kW to account for losses relating to low level RF [2]. Therefore the coupler has to be capable of handling 13 kW peak power, and operate at an average power of 1.5 kW with a loaded Q of 5×10^7 [3]. These requirements are summarised in Table 1.

COUPLER DESIGN

The HZB VSR coupler is a 50 Ω coaxial high power coupler (HPC) derived from the Cornell ERL injector coupler [5]. Figure 1, shows the basic RF design of the coupler with a WR-510 waveguide to coax transition at the warm end. Two ceramic alumina AL-300 windows with permittivity ε=9.4 and loss tangent tanδ=0.0003 preserve the cavity vacuum and act to support the inner conductor. The three sets of bellows allow for mechanical control of the coupler penetration depth and hence the level of coupling. Additionally the bellows act as temperature intercepts as seen in Fig. 1. The coupler has a rounded antenna tip which is better suited for the coupling level for VSR than the "pringle type" tip used for the Cornell ERL. Using such an antenna tip for VSR would result in over coupling.

To ensure a thorough design phase the materials of the coupler have been defined. The outer conductor is made from stainless steel, with the internal RF surfaces coated in 10 μm copper, to minimise the dynamic and static load. The inner conductor is fabricated from copper except for the inner bellows which will be copper coated stainless steel.

Simulations Results

The coupler design was performed using ANSYS HFSS [6]. The S-parameters were analysed to ascertain the transmission and hence the level of coupling provided. The coupler must fulfil the following S-parameter requirements; S_{11} must be below −40 dB at 1.5 GHz with a bandwidth below −30 dB of over 10 MHz.

To ensure the response of the coupler fit the above specifications small modifications were made to the initial coupler design via parameter sweeps. These modifications included; using a WR-510 input waveguide for 1.5 GHz operation, enlargement of the area around the cold window and adjustments to the transition from waveguide to coax. The most significant change was made to the coax dimensions, ensuring an impedance of 50 Ω.

The change in coax dimensions also allowed us to reduce the HOM propagation into the coupler as it raised the cut-off of the TE_{11} coax mode to above 2.75 GHz. This TE_{11} coax mode has a strong cavity HOM associated with it (± 50 MHz) which resulted in significant power levels propagating into the waveguide dampers and the coupler. Thus, raising the cut-off of this mode significantly reduced the impact of the HOM modes on operation.

After numerous tuning steps a design was settled on that fulfilled the S-parameter requirements. Figure 2 shows the

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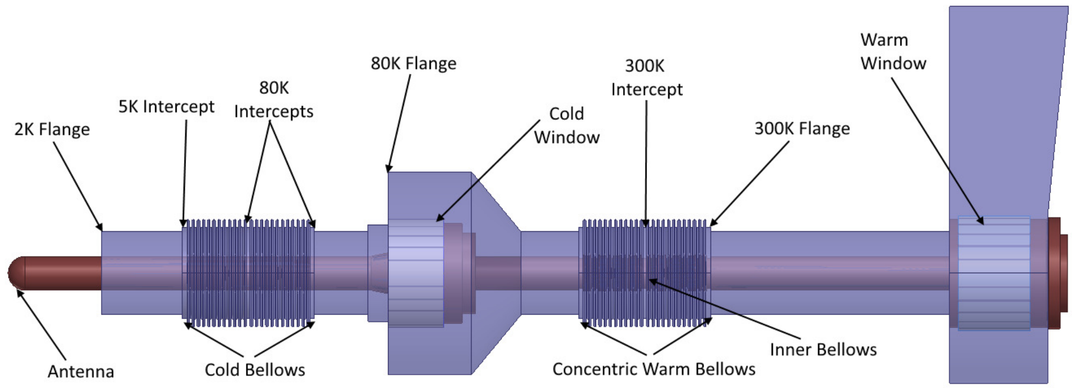

Figure 1: Basic RF design of the 1.5 GHz coupler showing only the vacuum and inner coupler. With temperature intercepts and components clearly labelled.

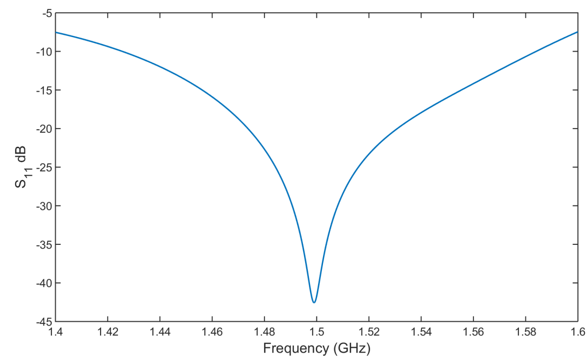

Figure 2: The S_{11} parameters for the final coupler design.

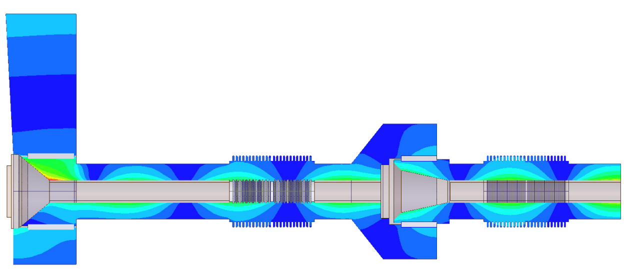

Figure 3: The magnetic field in the coupler for 16 kW input power.

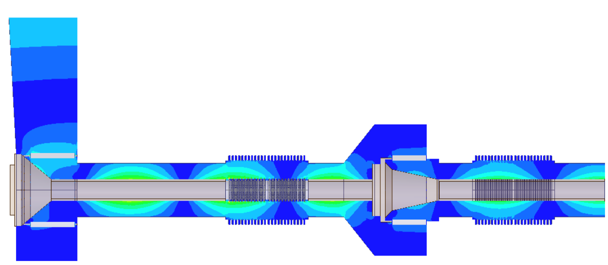

Figure 4: The electric field in the coupler for 16 kW input power.

S_{11} response of the final design of the coupler, with S_{11} of −42 dB at 1.499 GHz indicating strong coupling and a bandwidth of 16 MHz below −30 dB. Figures 3 and 4 show the magnetic and electric fields in the optimised coupler for 16 kW of travelling wave input power.

Bellows Tuning

The BESSY VSR HPC incorporates three sets of bellows to provide variable Q coupling by allowing mechanical control of the penetration depth of the coupler tip. By compression and expansion of the bellows the coupler tip can be moved further out of or further into the cavity. Simulations were performed for both compression and expansion of the bellows of up to 10% (approximately ±8 mm) to investigate how this effected the response of the coupler.

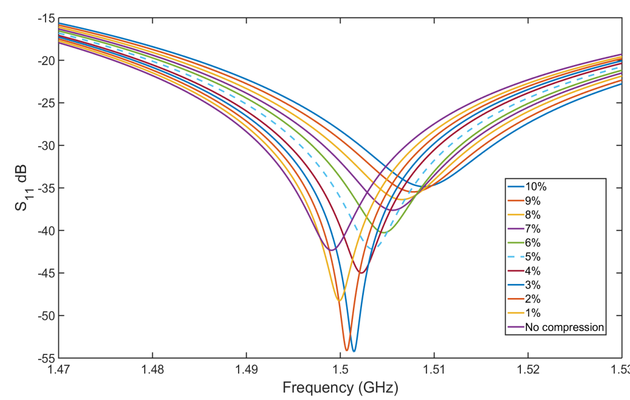

Figure 5: Change in S_{11} as the bellows are compressed by 10%.

Figure 5 shows the change in S_{11} for 10 % bellows compression. As the bellows compress, the bandwidth and frequency of the response increases. Due to the resonance condition introduced by the bellows, the magnitude of the response increases for compressions of 1 and 2 percent and then with further compression the magnitude decreases. For compression of up to 5% (dashed line) the response remains below −30 dB at 1.5 GHz, therefore satisfying the S-parameter requirements.

Results from expansion studies were similar. As the bellows expand the frequency and magnitude of the response decrease and the bandwidth increases. As with compression the response remains below −30 dB at 1.5 GHz for 5% expansion. This percentage change of 5% corresponds to a move of ±4 mm to the position of the coupler tip, allowing the coupler to have a tunable range of Q.

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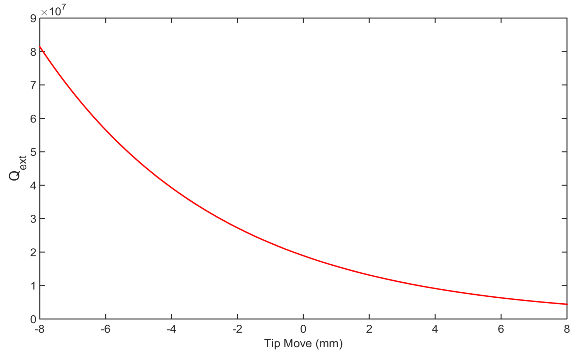

Figure 6: Change in Q_{ext} as the coupler penetration depth is increased and decreased.

Figure 6 shows the change in Q_{ext} as the coupler penetration depth is increased and decreased by 8 mm corresponding to 10% compression and expansion of the bellows. It can be seen that the bellows allow for a tunable range of Q_{ext} of $9.24{\times}10^6$ to $3.8{\times}10^7$ for 5% expansion and compression. Though the desired coupling range has not been met, these results are promising for initial coupler plus cavity simulations. With further tuning we should to be able to tune Q_{ext} over a full order of magnitude to give a coupling range of $6{\times}10^6$ to $6{\times}10^7$.

THERMAL STUDIES

Thermal analysis is important when considering high power systems, as high fields can lead to heating and associated thermal stresses which could cause the coupler to break down. To understand the thermal effects within the coupler, the materials of the inner and outer surfaces need to be considered and modelled, details of these are given in section 2.

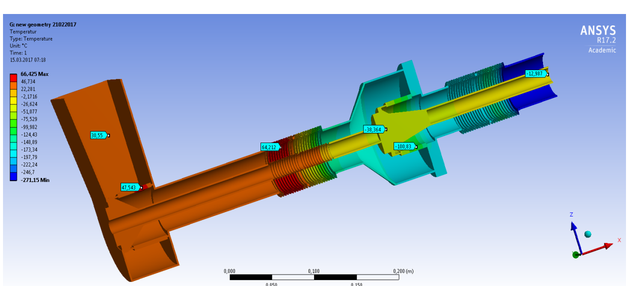

Figure 7: Thermal simulation for 16 kW travelling wave power.

Figure 7 shows the results of the thermal simulations of the coupler at 16 kW travelling wave power. Two clear temperature peaks are noted, a peak of 47° C at the first ceramic window and a peak of 64° C at the warm bellows between 300 K flange and intercept. The heating on the bellows cannot be mitigated via convection cooling due to the vacuum past the first ceramic window, however external water cooling could be used.

RF simulations of the coupler identified the warm window as an area of concern for high thermal stresses, due to the

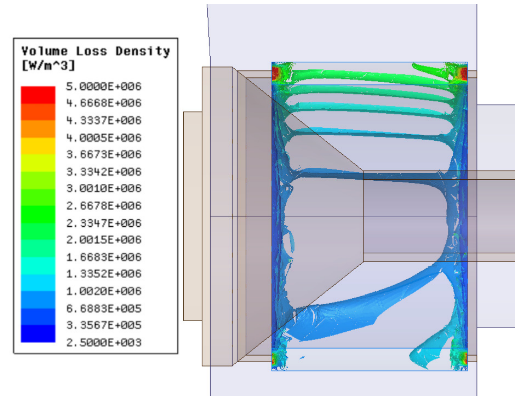

Figure 8: Volume loss density in the ceramic highlighting the point of high power loss that result in heating.

peak in the magnetic field just below the window as shown in Fig. 3, and the lossy nature of ceramics. Figure 8 shows the volume power loss in the ceramic for an input power of 16 kW. Areas of high power loss can be seen in the upper half of the ceramic, where the highest level of heating can be found. To mitigate this heating the ceramic window is cooled by compressed airflow with film coefficient 200 W/m^{2}K.

CONCLUSION

Design of the higher power 1.5 GHz couplers for BESSY VSR is almost complete. The coupler shows good transmission to the cavity at 1.5 GHz meeting the requirements of BESSY VSR. Initial Q_{ext} analysis has shown promising results and with further coupler modifications tunable coupling of up to one order of magnitude should be possible. Initial thermal tests have been performed and show some hot spots however these can be mitigated by integrated cooling. Further thermal analysis is planned to analyse heating of the coupler for all operational modes to ensure no breakdown can occur when the coupler is operational.

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