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BOOSTER CAVITY AND FUNDAMENTAL POWER COUPLER DESIGN ISSUES FOR bERLinPro*

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Abstract

HZB has started building the 50 MeV, 100 mA demonstrator energy-recovery-linac (ERL) facility bERLinPro. The high power injector system needs to deliver this beam at 6.5 MeV by combining the energy gain of a 1.4 cell SRF photo-injector and three Cornell style 2-cell booster cavities. One booster cavity will be operated at zero-crossing for bunch energy chirping. Thus two booster cavities have to deliver 2 MV each requiring a strong coupling with a loaded Q of 10^5. To house the two envisaged KEK fundamental power couplers (FPC) with the cavity, the geometry was slightly modified. Further, to increase coupling and reduce transverse kick effects to the beam, a "*golf-tee*" antenna tip was designed. This paper summarizes the SRF challenges for the booster cavities, the operational conditions and the modification to the KEK couplers, including tracking calculations to estimate the coupler kick effect to higher order.

INTRODUCTION

For the bERLinPro (see Fig. 1) ERL [1] the injector section will consist of a 1.4 cell SRF photo-injector cavity [2] delivering a 100 mA 2.3 MeV beam at a normalized emittance of ≤ 1 mm mrad and a module with 3 SRF booster 2-cell cavities of Cornell design [3]. The latter has to preserve the low emittance of the beam, accelerate it to the injection energy of the recirculator of 6.5 MeV and imprint an energy chirp for bunch compression. Table 1 summarizes the expected beam parameters from the SRF photo-injector cavity and the operating parameter for the booster cavities. To allow for an energy gain of 2.1 MeV per cavity the heavily beam-loaded structures have to be operated at a strong input coupling with a loaded Q of 10^5. To account for the high required forward power of 230 kW, it was decided to

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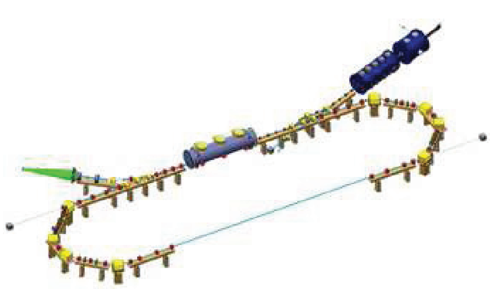

Figure 1: Scheme of the bERLinPro ERL with the injector section on the top right of the picture.

Table 1: Beam parameters as expected from the SRF photo-injector cavity as input parameter for the Booster coupler kick calculations and Booster cavity operating parameters.

$\epsilon_{n,y,x}$	1 mm mrad
σ_t	5 ps rms
$\sigma_{y,x}$	≈1.0 mm rms
$I_{avg,beam}$	100 mA
$E_{kin,ini}$	2.3 MeV
V_{acc}	2.1 MV
E_0	7, 19, 19 MV/m
Φ_{acc}	-90, 0, 0 deg

equip the cavity with two high power KEK-style coaxial couplers [4]. The coupler will have a fixed coupling providing matching conditions for full beam current. In order to reduce dipole-like coupler kicks and emittance growth and the power load limit of the coupler, two opposed couplers will provide the power to the cavity. However, to achieve the mandatory operational parameters, the cavity geometry and the coupler design had to be modified. To improve the coupling strength and to reduce the effects of higher order field deviations caused by the coupler, the antenna tip was modified. In the following sections the modified design will be discussed as well as its influence on the beam quality by tracking a bunch using 3D field maps.

THE MODIFIED BOOSTER CAVITY DESIGN

To house the large coaxial coupler with an outer conductor diameter of 82 mm, it was tapered to 70 mm and the beam tube on the coupler side was increased from 70 to 88 mm. Introducing a nose transition between the exit iris and the coupler beam tube, the reduction of the fundamental's R/Q could be limited to 0.4%. Further the level of peak field ratios remains unchanged compared to the original design. By that the penetration depth of the inner conductor into the beam tube would still be 14 mm for the target Q_L. To achieve

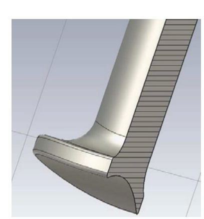

Figure 2: New "*golf tee*" shaped coupler tip to increase the coupling strength and reduce coupler kick effects.

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a stronger coupling at less penetration the antenna tip was modified to a so called "*golf tee*" shape which is described by Viviani's curve, see Figure 2. By optimizing the ellipse aspect ratio of the tip's surface, its thickness and the blending edge of the opening to the outer conductor the target Q_L was achieved at 3 mm penetration. The distance between coupler and cavity exit iris was limited by the need to house the helium vessel of the cavity in between. In Table 2 the calculated RF properties of the modified structure are given. The shown Q_{ext} of the first two dipole bands assume perfect absorption by beam tube HOM absorbers downstream of the cavity.

Table 2: Calculated RF parameters of the Booster cavity with two coaxial modified KEK type couplers.

Number of cells	2
$R/Q_{\parallel}$	219 Ω
f_{RF}	1.3 GHz
E_{peak}/E_{acc}	2.0
B_{peak}/E_{acc}	4.4 mT/MVm^{-1}
Q_{ext} TE_{111} dipole	130, 370
Q_{ext} TM_{110} dipole	170, 7300
Q_L at 3mm penetration depth	$1.05 \cdot 10^5$
$P_{forward}$	230 kW

COUPLER KICK AND EMITTANCE DILUTION CALCULATIONS

To evaluate the new coupler design and prove their feasibility to maintain the high beam quality, coupler kick calculations were performed using 3D field maps calculated by CST MWS [7] using the new hexahedral mesh of version 2014. The fields were calculated with electric and magnetic boundary conditions to not only simulate the standing wave (SW) regime of the low beam current mode of operation, but also the traveling wave (TW) scenario with full beam current accelerated. Further the on axis fields were crosschecked with Superfish [8] to check the mesh quality and to rule out any unwanted offsets.

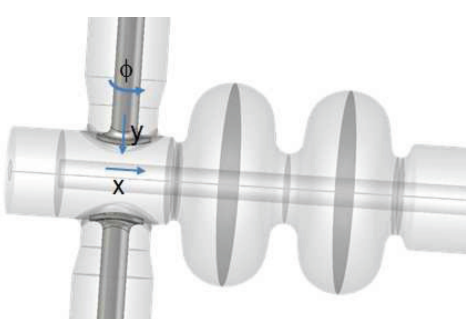

Figure 3: Misalignment scenarios studied for the modified KEK coupler as attached to the 2-cell SRF booster cavity. The upper inner conductor is shifted with respect to the opposing FPC port in x and y and (for the "*golf tee*" only) rotated in ϕ.

Two methods were used to calculate the kick to the beam and the emittance dilution neglecting space charge. The obtained field maps were imported within CST into the PS Particle In Cell (PIC) tracking solver and a bunch with bERLinPro phase space parameter created externally by ASTRA [9] served as the initial particle distribution. The PIC results were compared with the outcome of ASTRA runs using 3D ASCII exported (step 1 mm) field maps of the same CST eigenmode simulation. Several scenarios were studied for acceleration phases of +90, 0 and -90 deg.:

- The bare cavity structure as reference
- Twin original KEK couplers, aligned and misaligned
- Twin modified "*golf tee*" couplers, aligned and misaligned + angle (rotation in ϕ)
- Single coupler with design Q_L

Figure 3 shows the misalignment scenarios studied with simulations. The greatest influence is by an error in the relative penetration depth of the two antennas and for the "*golf tee*" type the rather improbable shift of the inner conductors angle with respect to the coupler axis. For this study a rather pessimistic alignment error of 3 mm vertical and 2 mm in horizontal direction was assumed. Figure 4 shows the on-

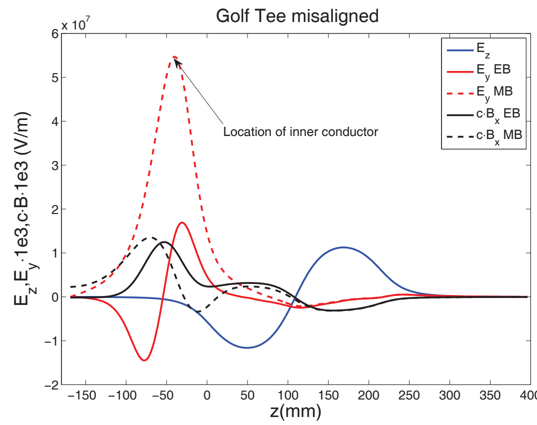

Figure 4: On-axis longitudinal and transverse field components for a misaligned "*golf tee*" coupler pair with EB and MB conditions.

axis field components E_y and $c \cdot B_x$ which mostly contribute to the deviation from the ideally rotational symmetric transverse fields of the bare cavity. Here the misaligned scenario is compared for electric and magnetic coupler wall boundary (EB, MB). But even in the perfectly aligned case a twin coupler set-up might just shift the field deviation to higher order imposing quadrupole like additional focusing on the beam. That effect is addressed with the 3D calculations as well.

First Results

The kick induced in the vertical plane by a misaligned twin coupler is displayed in Figure 5. Kicks of the level of 0.4 mrad are observed. This agrees very well with the ASTRA simulations showing 0.5 mrad. The calculated emittances agree also very well between both methods, only for

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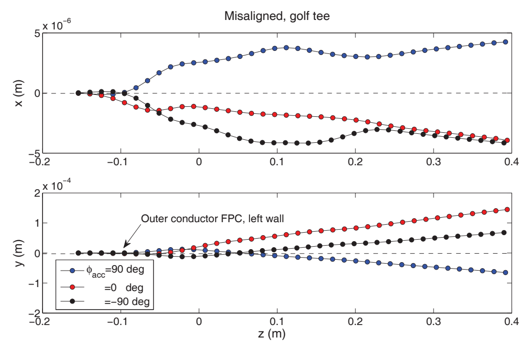

Figure 5: Kick induced by a misaligned twin coupler for a 5 ps bunch by PIC calculations. The position of the coupler by the opening of the outer conductor is marked by the black arrow.

ϕ_{acc}=+90 deg the deviation is about a factor of 5, but the difference between coupler and bare cavity differs by only 0.5 % (see Figure 6). This will be investigated further.

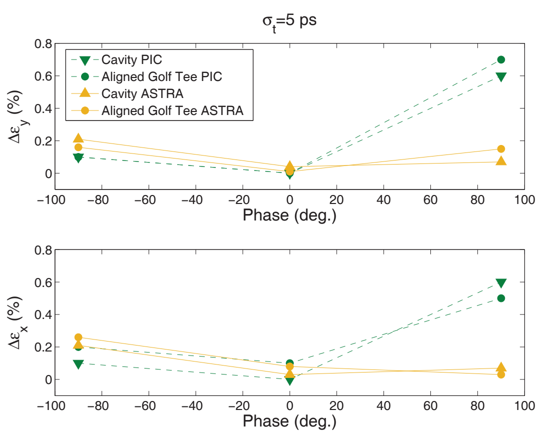

Figure 6: Comparison of the normalized emittance growth relative to the initial value for an aligned twin coupler scenario and the bare cavity using CST PIC and ASTRA.

SUMMARY AND OUTLOOK

Comparing the results for the different scenarios and coupler types (Figure 7) one can summarize:

- For a similar misalignment scenario the "*golf tee*" coupler is less perturbing the beam's emittance than the original KEK design (blue vs. green curve)
- In the misaligned case the emittance growth is on the percent level, but there is a rather strong kick at 0.4 mrad
- For an aligned twin "*golf tee*" the emittance growth is negligible ($\leq$1e-3) and the focusing strength changes by 10 % with a 3 % imbalance between both vertical planes in the misaligned case (on-crest)

For following studies the TW case will be analyzed in more detail, even during the ramping of the beam current, when the fields in the coupler switch from SW to TW regime. Similar studies are also planned for the high current SRF photo-injector cavity, as this might have an influence on the injector optics.

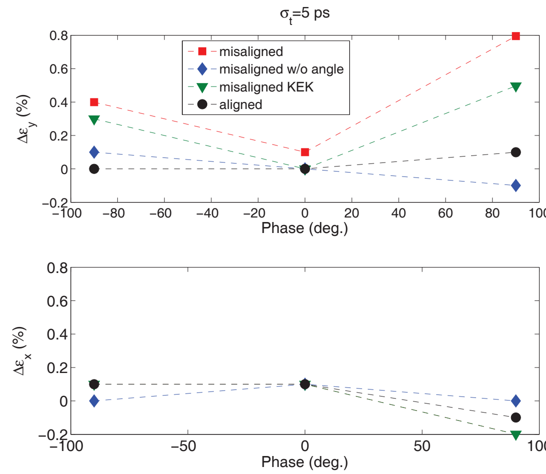

Figure 7: Relative emittance growth in both vertical planes versus ϕ_{acc} for the different scenarios studied for the first booster cavity behind the SRF photo-injector in reference to the bare cavity using the PIC code.

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