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 $\leq 1$ 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 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

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon_{n,y,x}$</td>
<td>1 mm mrad</td>
</tr>
<tr>
<td>$\sigma_t$</td>
<td>5 ps rms</td>
</tr>
<tr>
<td>$\sigma_{y,x}$</td>
<td>$\approx 1.0$ mm rms</td>
</tr>
<tr>
<td>$I_{avg,beam}$</td>
<td>100 mA</td>
</tr>
<tr>
<td>$E_{kin,inj}$</td>
<td>2.3 MeV</td>
</tr>
<tr>
<td>$V_{acc}$</td>
<td>2.1 MV</td>
</tr>
<tr>
<td>$E_0$</td>
<td>7, 19, 19 MV/m</td>
</tr>
<tr>
<td>$\Phi_{acc}$</td>
<td>-90, 0, 0 deg</td>
</tr>
</tbody>
</table>

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

Figure 2: New "golf tee" shaped coupler tip to increase the coupling strength and reduce coupler kick effects.
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 Q₉

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

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

axis field components $E_x$ 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
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.

\[ \phi_{\text{acc}} = 90 \text{ deg} \]

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 (\( \leq 1 \times 10^{-3} \)) 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.

REFERENCES