Design of a third harmonic cavity with low R/Q for the ESR in BNL EIC

Binping Xiao
Brookhaven National Laboratory, Upton, New York 11973-5000, USA

Introduction

In the BNL EIC ESR, counter-phasing was studied to be used to fight against beam loading of the 1st harmonic and possible 3rd harmonic accelerating cavities. There are drawbacks of using this technique, such as higher RF power, higher power dissipation on cryo system, limited working conditions, etc. A better way to ease the beam loading effect, is to design a cavity with lower R/Q while maintaining the other RF parameters. In this paper, we describe cavity designs with effective length longer than half of the working mode’s wavelength, and with large beampipes that connected to the cavity with chokes, so that peak fields can be controlled at certain cavity voltage while R/Q can be lowered, and higher order modes (HOMs) can be damped using beampipe absorber. We also present the multipacting analysis, as well as a special fundamental power coupler (FPC) design.

Cavity design

<table>
<thead>
<tr>
<th>pCDR design</th>
<th>Design goal</th>
<th>New 1-cell design</th>
<th>New 2-cell design</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/Q [Ω]</td>
<td>51.5</td>
<td>17</td>
<td>20.7</td>
</tr>
<tr>
<td>Bpk [mT]</td>
<td>82.4</td>
<td>80.0</td>
<td>115.6</td>
</tr>
<tr>
<td>Epk [MV/m]</td>
<td>37.4</td>
<td>40.0</td>
<td>19.1</td>
</tr>
</tbody>
</table>

Top plot of left figure: new 1-cell design: elliptical cavity with 0.85R, with RF parameters shown in table. It is possible to use π mode, with field pattern similar to the TM011 mode in a 1-cell cavity. A new design with endplate nonconcentric to the inner conductor is used, shown on the left of Figure on the left figure: new 2-cell design, bottom of left figure with 72mm ID FPC port. Possible further optimizations to lower peak fields:

1. Use more 1-cell cavities or 2-cell cavities (either 0 mode or π mode). Cavity design with cells more than 2 might bring trapped modes within cells.
2. Fine tune the shape of the straight section.
3. While lengthen the cavity, instead of squeezing the end plates, the center of the cavity is squeezed to slightly increase the external quality factor Q_{ext} of the HOMs.

Cylindrical cavity without beampipe, with TM010 the working mode at \( f_0 \) with wavelength \( \lambda \):

- all HOMs in TM configuration (longitudinal HOMs) have frequencies higher than \( f_0 \), with the lowest frequency (TM011) for cavity with length \( \geq \lambda/2 \).
- For HOMs in TE configuration (transverse HOMs), the TE_{111} mode has the lowest resonant frequency, and with cavity length increasing from \( \lambda/2 \), its frequency starts to come closer to, and might be even lower than \( f_0 \).

Figure on the left, from top to bottom:

1. 1st plot, for a \( \lambda/2 \) pillbox cavity, the frequency of TM_{011} mode is \( \sqrt{2}f_0 \), and for TE_{111} it is 1.26\( f_0 \).
2. 2nd plot, with cavity length increases to \( \lambda \), these two values change to \( \sqrt{5}/2f_0 \) and 0.914\( f_0 \), respectively.
3. 3rd plot, while taking the beampipe into account, since the cutoff frequency of TE_{11} is lower than that of TM_{01} in a beampipe, with a reasonable big opening, TE_{111} can leak out of the cavity, even with its frequency closer to or lower than \( f_0 \). Such a beampipe can also be used to extract TM_{011} mode. The drawbacks of using large beampipe: the frequencies of these two HOMs will be lowered with larger beampipe, causing them difficult to leak out, and the R/Q of the working mode will also be lowered and causing higher Bpk at certain Vacc.
4. 4th plot, similar to the pCDR design, choking the beampipe is a solution, with the cost of increasing external quality factor Q_{ext} of the HOMs.

With a cavity length at 0.7\( \lambda \), and beampipe radius of 0.8R, with R the cavity radius, and iris radius of 0.4R, the R/Q of this cavity can be suppressed to 21.5Ω, with 106.9mT Bpk and 46.6MV/m Epk at 1.6MV Vacc.

Top plot of left figure: new 1-cell design: elliptical cavity with 0.8\( \lambda \) length. It has a lower Epk while comparing with the pillbox design due to the elimination of sharp edges on the iris, and a higher Bpk since the magnetic field is more concentrated to the center of the cavity. In short, stretching the 3rd harmonic cavity design in pCDR to a longer version can lower the R/Q.

Bottom plot of left figure:

Possible further optimizations to lower peak fields:

1. Use more 1-cell cavities or 2-cell cavities (either 0 mode or π mode). Cavity design with cells more than 2 might bring trapped modes within cells.
2. Fine tune the shape of the straight section.
3. While lengthen the cavity, instead of squeezing the end plates, the center of the cavity is squeezed to slightly increase the R/Q so that a lower peak fields can be achieved at certain Vacc.

All three methods result the same cavity geometry (new 2-cell design, bottom of left figure with 72mm ID FPC port). It is possible to use π mode, with field pattern similar to the TM_{011} mode in a 1-cell cavity.

A new design with endplate nonconcentric to the inner conductor is used, shown on the left of bottom plot, to achieve 5.9e4 FPC Q_{ext} with 72mm ID FPC port.

Acknowledgement

The work is supported by Brookhaven Science Associates, LLC under contract No. DE-AC02-98CH10886 with the US DOE. The authors would like to thank T. Xin for the useful discussion and the multipacting simulation using FishPact.