Calculation of the Coupling Impedances of Holes and Slots on the Liner Using MAFIA and Scaling

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Abstract

The location of a liner inside the beam tube is one of the options considered for the Super Colliders (SSC—Superconducting Super Collider and LHC—Large Hadron Collider). The liner could serve as a synchrotron radiation intercept and also help enhance the vacuum. A definite distribution of holes or slots is required to be located on the liner for pumping out the desorbing gases. There will be wake fields propagating within the liner due to diffraction at discontinuities (holes, slots, bellows, etc.) following the incident beam fields. The effect of these wake fields can be minimized by adopting the least number of pumping holes/slots required and through an optimal choice of hole/slot shape and size. The effect of the wake fields on the beam may be expressed through coupling impedances defined proportional to the corresponding forces integrated through distance per unit charge. It is necessary to compute the impedance of holes and slots and determine the scaling of the impedance with the dimensions of the hole/slot and the liner, in order to optimize the choice of pumping holes/slots. The coupling impedances of slots and holes have been calculated here using the code MAFIA and the scaling assessed. The results compare favorably with existing analytical results.
1.0 INTRODUCTION

The introduction of a liner inside the beam tubes of super colliders (the Superconducting Super Collider—SSC, and the Large Hadron Collider—LHC) serves many purposes. The liner could serve as a synchrotron radiation intercept. If the liner could be maintained at a high temperature, the incident energy could be removed efficiently. The discontinuities in the liner will result in wake fields propagating inside the liner. These fields will act on successive bunches and could result in bunch lengthening, instabilities and emittance growth. The liner will help enhance the vacuum; one needs to provide an appropriate number and distribution of slots/holes on the surface of the liner for removing the desorbing gases. We have the advantage of optimizing and minimizing the number of holes and thus minimize the effect of the wake fields on the beam.

The effect of the wake fields on the beam bunches may be expressed quantitatively through the longitudinal or transverse coupling impedances of the slots or holes, which are defined proportional to the integrated force (longitudinal or transverse) per unit charge.\(^1\)\(^-4\) The coupling impedance of round holes on the liner of LHC and SSC have been studied analytically by Gluckstern\(^5\) and Kurennoy\(^3\) for low frequencies, where the dimension of the hole is much smaller than the wave length of the incident field. Kurennoy\(^6\) has obtained a formula for the coupling impedance of slots using the expressions of magnetic and electric polarizabilities from McDonald.\(^7\)\(^,8\) We have computed here the coupling impedances of slots and holes of various dimensions using the code MAFIA.\(^9\) We have obtained scaling relations for the coupling impedances and compared them with the values obtained using expressions from Gluckstern and Kurennoy.\(^3,5,6\)

2.0 DESCRIPTION OF THE PROBLEM

A schematic of the beam pipe and the liner is shown in Figure 1. The liner of inner radius \(a\) and thickness \(\Delta\) is located inside the beam tube of radius \(b\). A slot of length \(w\) and width \(d\) is located on the liner. The center of the slot is situated at \(z = 0.0\). In the case of round holes we will denote the diameter of the hole by \(d\). The coordinate system is shown in Figure 1. The longitudinal impedance is defined as follows:\(^3\)

\[
Z(\omega) = -\frac{1}{q} \int_{-\infty}^{\infty} E_z(r = 0, \theta = 0) e^{ikz} \, dz \tag{1}
\]

where \(k = \frac{\omega}{c}\).
all cases. The beam modeled for all cases was Gaussian with a \( \sigma = 0.25 \) cm extending up to 5 \( \sigma \)'s in the positive and negative \( z \) directions. In the case of the transverse impedance, the beam was offset 1 mm from the axis in the positive \( x \) and \( y \) directions. In the case of the longitudinal wakes alone, one quarter of the structure was modeled and the length increased to 50 cm. For the cases where the radius \( a \) of the liner was varied, the thickness \( \Delta \) was maintained at 1 mm and the air gap between the liner and the beam tube was maintained at 4 mm.

Figure 1(a). 3D plot of the slot distribution, 20-cm liner with 32 2 \( \times \) 12 slots, randomly distributed.

All the wake fields were calculated with irregular distributions of holes or slots. For the case of longitudinal wake fields and impedances 184 holes were modeled except for the 2 \( \times \) 12 mm and 2 \( \times \) 20 mm cases, where only 60 slots were simulated. For the transverse wake fields and impedances, 80 openings were simulated for all but the cases with the two longest slots where only 32 slots were used. The strategy was to incorporate as many openings as possible for the strongest possible signal with the length in \( z \) as long as could be accommodated within the limitations of the code.

2.1 The Longitudinal Coupling Impedance of Round Holes

The expression for the longitudinal coupling impedance of holes at low frequencies obtained by Gluckstern and Kurennoy\(^{5,6} \) is:

\[
Z = \frac{jZ_0kd^3}{6\pi^2a^2}
\]  

(2)
Table 1. Variation of the Longitudinal Impedance with the Radius of the Liner.

<table>
<thead>
<tr>
<th>Liner I.D. (cm)</th>
<th>Frequency (GHz)</th>
<th>Impedance (mohms)</th>
<th>( Z = Z_{0.35} (1.35) ) (mohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.35</td>
<td>5.270</td>
<td>18.32</td>
<td>18.32</td>
</tr>
<tr>
<td>1.65</td>
<td>5.270</td>
<td>12.02</td>
<td>12.28</td>
</tr>
<tr>
<td>1.95</td>
<td>5.270</td>
<td>8.936</td>
<td>8.780</td>
</tr>
</tbody>
</table>

Figure 3. Longitudinal coupling impedance of holes.

Table 2. Longitudinal Coupling Impedance of Holes.

<table>
<thead>
<tr>
<th>Hole Dia. (mm)</th>
<th>Freq. (GHz)</th>
<th>Imped. (mohms)</th>
<th>( Z = Z_{3 \text{ mm}} (\frac{3}{3})^3 )</th>
<th>Imped. (mohms)</th>
<th>Corrected Imped. (mohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.977</td>
<td>1.580</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.977</td>
<td>4.696</td>
<td>1.391</td>
<td>2.447</td>
<td>1.390</td>
</tr>
<tr>
<td>5</td>
<td>4.977</td>
<td>22.76</td>
<td>21.74</td>
<td>19.58</td>
<td>25.200</td>
</tr>
</tbody>
</table>

2.2 The Longitudinal Coupling Impedance of Slots

Kurennoy\(^4\) has obtained the following analytical expressions for the longitudinal coupling impedance of a slot. From the general expressions of References 3, 5:

\[
Z = j Z_0 k \frac{(\alpha_m + \alpha_s)}{4 \pi^2 \alpha^2},
\]

(3)
Figure 4. Longitudinal impedance of slots with various widths, $w$.

Figure 5. Longitudinal coupling impedance of slots with various depths, $d$. 
The transverse impedance per round hole reduces from Eq. (8) to

\[ Z_t = j \frac{Z_0}{2\pi^2} \frac{d^3}{a^4}. \]  

In the case of slots with \( w > d \) Eq. (8) reduces to

\[ Z_t = j \frac{Z_0}{2\pi^2} \frac{d^3}{a^4} \left( 0.1814 - 0.0344 \frac{d}{w} \right). \]

The transverse impedances (per hole or slot) computed from MAFIA for holes and slots are shown in Figures 7 and 8.

The \( d^3 \) dependence and \( k^0 \) dependence indicated by Eqs. (8) and (9) are corroborated by the MAFIA results.

![Figure 7. Transverse impedance of holes.](TIP-05101)
ACKNOWLEDGEMENTS

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REFERENCES


APPENDIX
Input File
Following is the input file for m310 for calculating the longitudinal wakes for 60 2x12 slots using a quarter geometry.

```
#file t m a o stat=unk name=m ex
#file t p a o stat=unk ex
#file t l a o stat=unk ex
#general
text(1)="50cm liner with 60 2 x 12 slots, randomly distributed, July 1993"
text(2)="quarter geometry; bunch sigma=0.25cm"
#general scale=0.01
#mesh
xm 0.0 s43 2.15
ym 0.0 s43 2.15
zm -25.0 s 500 0.00 s500 25.0 ex
#brick
mat=1 vol= 0.0 +2.15 0.0 +2.15 -25.0 +25.0 ex
#cyl
mat=0 fill=diag ori=z range=-25.0 +25.0 center 0.0 rad=2.15
part=quarter which=+x+y ex
mat=1 center=0.0 rad=1.75
part=quarter which=+x+y ex
mat=0 rad=1.65
part=quarter which=+x+y ex
#brick
mat=3 vol 0.000 0.100 1.650 1.750 -21.100 -19.900 ex
mat=3 vol 0.000 0.100 1.650 1.750 -18.900 -17.700 ex
mat=3 vol 0.000 0.100 1.650 1.750 -16.550 -15.350 ex
mat=3 vol 0.000 0.100 1.650 1.750 10.200 11.400 ex
mat=3 vol 0.000 0.100 1.650 1.750 -13.700 -12.500 ex
mat=3 vol 0.000 0.100 1.650 1.750 15.900 17.100 ex
mat=3 vol 0.000 0.100 1.650 1.750 18.100 19.300 ex
mat=3 vol 0.000 0.100 1.650 1.750 -5.250 -4.050 ex
mat=3 vol 0.000 0.100 1.650 1.750 -1.600 -0.400 ex
mat=3 vol 0.000 0.100 1.650 1.750 -11.500 -10.300 ex
mat=3 vol 0.000 0.100 1.650 1.750 -9.300 -8.100 ex
mat=3 vol 0.000 0.100 1.650 1.750 5.100 6.300 ex
mat=3 vol 0.000 0.100 1.650 1.750 0.600 1.800 ex
mat=3 vol 0.000 0.100 1.650 1.750 2.800 4.000 ex
mat=3 vol 0.000 0.100 1.650 1.750 7.300 8.500 ex
$
mat=3 vol 1.650 1.750 0.000 0.100 -13.600 -12.400 ex
mat=3 vol 1.650 1.750 0.000 0.100 11.050 12.250 ex
mat=3 vol 1.650 1.750 0.000 0.100 8.300 9.500 ex
mat=3 vol 1.650 1.750 0.000 0.100 -9.650 -8.450 ex
mat=3 vol 1.650 1.750 0.000 0.100 4.250 5.450 ex
mat=3 vol 1.650 1.750 0.000 0.100 -4.950 -3.750 ex
mat=3 vol 1.650 1.750 0.000 0.100 17.600 18.800 ex
mat=3 vol 1.650 1.750 0.000 0.100 -2.750 -1.550 ex
mat=3 vol 1.650 1.750 0.000 0.100 -17.600 -16.400 ex
mat=3 vol 1.650 1.750 0.000 0.100 -7.450 -6.250 ex
mat=3 vol 1.650 1.750 0.000 0.100 -0.550 0.650 ex
mat=3 vol 1.650 1.750 0.000 0.100 19.800 21.000 ex
mat=3 vol 1.650 1.750 0.000 0.100 1.650 2.850 ex
mat=3 vol 1.650 1.750 0.000 0.100 13.250 14.450 ex
mat=3 vol 1.650 1.750 0.000 0.100 -21.100 -19.900 ex
$
stop
```
Following is the input file for p310 for calculating the longitudinal wakes for 60 2x12 slots using the whole geometry.

#file act=op type=log status=unknown name=p ex
type=print act=op stat=unk ex
type=maf act=op stat=old ex
#list
  sym=general ex
  items=1024 symb=wz/bun ex
stop
Following is the input file for t3310 for calculating the transverse wakes for 32 2x12 slots using the whole geometry.

```plaintext
printscreen
#file act=op type=log status=unknown name=t ex
    type=print act=op stat=unk ex
    type=maf act=op stat=old ex
#boun
    xboun=elec,elec yboun=elec,elec, zboun=waveguide, waveguide
#mat
    mat=1 type=elec
    mat=0 eps=1
    mat=3 eps=1
    show
#beam
    sigma=0.0025 xpos=0.001 ypos=0.001 charge=1.0 bunch=gauss return
#monitor
    symb=wz/bun field=wz
    xlo=0.001 xhi=0.001 ylo=0.001 yhi=0.001 sloc=0.00 shi=0.512 ex
    symb=wx/bun field=wx ex
    symb=wy/bun field=wy ex
    show
#time
    mt=4 nend=0 integer00
    menu
#control
    check dumpsave=no map=3
    execute
end
```

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