Transient behavior of NLC damping ring cavities

What’s Important?

- Voltage transient during gap
- Power dissipated in cavity and total power required
- Cavity wall power density
- HOM damping
Voltage transient

For step change I in beam current, transient voltage $V(t)$ given by:

$$V(t) = 2I_0 R(1-e^{-t})\sin(\omega_0 t)$$

where

$$R = \frac{R_s}{Q_o} \times Q_L$$

$$\tau = \frac{2Q_L}{\omega_0}$$

for

$$t << \tau$$

envelope is approx.:

$$V(t) = 2I_0 \frac{R_s}{Q_o} \times Q_L \times \frac{\omega_0}{2Q_L}$$

so

$$V(t) \propto \frac{R_s}{Q_o}$$

So we want to lower $R/Q$ by about a factor of 10 to get acceptable phase variation along train.
Compare some cavity shapes:

<table>
<thead>
<tr>
<th>PEP-II type (714a)</th>
<th>714b</th>
<th>bell</th>
<th>TM020</th>
<th>sphere</th>
<th>sphere</th>
<th>sphere</th>
<th>sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of cells</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>R/Q (Ω)</td>
<td>117</td>
<td>118</td>
<td>73.0</td>
<td>52.3</td>
<td>25.5</td>
<td>25.5</td>
<td>9.42</td>
</tr>
<tr>
<td>“improvement”</td>
<td>1.00</td>
<td>0.99</td>
<td>1.60</td>
<td>2.24</td>
<td>4.59</td>
<td>3.44</td>
<td>12.42</td>
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<tr>
<td>power/cell (kW)</td>
<td>41.4</td>
<td>41.4</td>
<td>57.5</td>
<td>66.5</td>
<td>126.8</td>
<td>71.3</td>
<td>312.5</td>
</tr>
<tr>
<td>approx. total power (kW)</td>
<td>713</td>
<td>713</td>
<td>761</td>
<td>788</td>
<td>969</td>
<td>874</td>
<td>1526</td>
</tr>
<tr>
<td>max Pw (2D) W/cm²</td>
<td>23.0</td>
<td>22.0</td>
<td>25.4</td>
<td>24.5</td>
<td>56.1</td>
<td>31.5</td>
<td>144.0</td>
</tr>
<tr>
<td>12.5 cm pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Reduce R/O by increasing transit time?

For pillbox R/Q goes to zero as length goes to nλ.

<table>
<thead>
<tr>
<th>Model</th>
<th>R/Q</th>
<th>Power Range (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM010</td>
<td>10</td>
<td>250-275</td>
</tr>
<tr>
<td>TM010</td>
<td>20</td>
<td>125-175</td>
</tr>
<tr>
<td>TM020</td>
<td>10</td>
<td>130-210</td>
</tr>
<tr>
<td>TM020</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>(WQ</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>105</td>
<td>kW</td>
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</table>
Variation of pillbox parameters with length
(TM010 mode, URMEL calculations, 714 MHz)

Parameters of TM010 mode in pillbox as a function of length
Power required to maintain 500 kV gap voltage as a function of length and R/Q
Variation of pillbox parameters with length
(TM020 mode, URMEL calculations, 714 MHz)

Parameters of TM020 mode in pillbox as a function of length
Power required to maintain 500 kV gap voltage as a function of length and R/Q
<table>
<thead>
<tr>
<th>PEP-II type</th>
<th>714b</th>
<th>bell</th>
<th>TM020</th>
<th>sphere</th>
<th>sphere</th>
<th>sphere</th>
<th>sphere</th>
<th>TM020</th>
<th>sphere 12.5cm beam pipe</th>
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</thead>
<tbody>
<tr>
<td>number of cells</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>R/O (Ω)</td>
<td>117</td>
<td>116</td>
<td>73.0</td>
<td>52.3</td>
<td>25.5</td>
<td>25.5</td>
<td>25.5</td>
<td>1.623</td>
<td>9.42</td>
</tr>
<tr>
<td>0 Ω × 70%</td>
<td>25664</td>
<td>25663</td>
<td>29799</td>
<td>35916</td>
<td>41393</td>
<td>41393</td>
<td>41393</td>
<td>116679</td>
<td>42499</td>
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<tr>
<td>Rs(MΩ)</td>
<td>3.02</td>
<td>3.02</td>
<td>2.175</td>
<td>1.88</td>
<td>0.986</td>
<td>0.986</td>
<td>0.986</td>
<td>0.161</td>
<td>0.4</td>
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<tr>
<td>volts/cell</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>375</td>
<td>300</td>
<td>500</td>
<td>375</td>
<td>300</td>
</tr>
<tr>
<td>power/cell</td>
<td>41.4</td>
<td>41.4</td>
<td>57.5</td>
<td>66.5</td>
<td>126.0</td>
<td>71.3</td>
<td>45.6</td>
<td>690.6</td>
<td>312.5</td>
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<tr>
<td>beam power/cell</td>
<td>196.3</td>
<td>196.3</td>
<td>196.3</td>
<td>196.3</td>
<td>147.2</td>
<td>117.6</td>
<td>1.96</td>
<td>196.3</td>
<td>147.2</td>
</tr>
<tr>
<td>beta (1+Pb/Pc)</td>
<td>5.7</td>
<td>5.7</td>
<td>4.4</td>
<td>4.0</td>
<td>2.5</td>
<td>1.1</td>
<td>1.6</td>
<td>1.3</td>
<td>1.6</td>
</tr>
<tr>
<td>U (J)</td>
<td>0.240</td>
<td>0.240</td>
<td>0.362</td>
<td>0.532</td>
<td>1.170</td>
<td>0.656</td>
<td>0.421</td>
<td>17.2</td>
<td>2.96</td>
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<tr>
<td>Qmax wall power (2D) W/cm²</td>
<td>23.0</td>
<td>22.0</td>
<td>25.4</td>
<td>24.5</td>
<td>56.1</td>
<td>31.5</td>
<td>20.2</td>
<td>334.9</td>
<td>144</td>
</tr>
<tr>
<td>Improvement 0V/60 pspl type</td>
<td>1.00</td>
<td>0.99</td>
<td>1.60</td>
<td>2.24</td>
<td>4.59</td>
<td>3.44</td>
<td>2.75</td>
<td>72.09</td>
<td>12.42</td>
</tr>
</tbody>
</table>
HOM damping

**TM010:** cavity HOMs can be damped by same techniques as PEP-II
(large bore case may require dampers on beam pipe)

**TM020:** One or more modes below accelerating mode, will require coaxial load.
Many more modes in larger volume (- 74 cm diameter x ~ 68 cm length)
Conclusions

Factor of a few (maybe 5) could be possible with modified TM010 cavities, one klystron

New cavity design required, engineering challenges.

Factor of 10 may be possible using

**TM020** cavity with long transit time, one klystron

4 spherical cavities with large bore, two klystrons

New cavity designs required, engineering challenges

Further questions

What about other modes, e.g.: **TM030, TM011**?

What about external energy storage cavity, e.g.: CERN, KEK-ARES?