Additional simulations of emittance correction in the damping rings are needed, including the effects listed in Section 7.2.3.2. Additional experiments in the ATF and other operating rings are needed to test the emittance correction algorithms.

Summary:
Since the publication of the 2003 ILC-TRC report:

- The KEK Accelerator Test Facility (ATF) has achieved a vertical emittance of 4 pm, exceeding the specification for the NLC Main Damping Rings.
- The ALS at LBNL has upgraded the hardware used for coupling correction, and also has indications of a vertical emittance of 5 pm (close to the resolution limit of the diagnostics).
- The lattice design for the NLC Main Damping Rings has been revised, reducing the sensitivity of the vertical emittance to magnet alignment errors. This design and an updated design for the positron pre-damping ring have become the GLC baseline.
- Observations with improved beam size diagnostics at the ATF have provided evidence for the validity of the Bjorken-Mtingwa theory of Intrabeam Scattering (IBS) in the regime in which the NLC/GLC damping rings will operate [1]. Calculations for the Main Damping Rings indicate that IBS will not prevent the specified emittance being reached.

Recent results:
The progress at the ATF prototype damping ring has been partly as a result of work done on the BPM system. Previous attempts at coupling correction relied on BPMs that had a resolution of around 20 µm; an upgrade of the BPM electronics has improved this to a resolution of better than 5 µm. Beam-based alignment studies also provided useful information allowing reduction of the coupling. Finally, an upgrade of the laser wire now allows reliable measurement of vertical emittances in the few pm range. The recent results are reported in [1]. The algorithm used is the same as previously, based on combined orbit and dispersion correction, and use of skew quadrupoles for minimizing the cross-plane orbit response to steering magnet kicks.

Also reported in [1] are measurements of the variation of the emittances with bunch intensity. IBS makes a significant contribution to the growth of emittance with intensity in the ATF at low vertical emittance, and this is also expected to be the case in the comparable parameter regime of the NLC/GLC Main Damping Rings. With the improved beam size diagnostics at the ATF, there now appears good agreement between the observed intensity dependence of the emittance and calculations of IBS based on the Bjorken-Mtingwa theory [2].

At the ALS, additional power supplies were installed early in 2003, to provide a larger number of independently adjustable skew quadrupoles. An analysis of the closed-orbit response matrix was used to determine local sources of coupling, and the appropriate strengths of the skew quadrupoles needed to minimize the coupling. Estimates of the vertical emittance were made using the synchrotron light monitor and the Touschek
Lifetime. Although definite results are difficult to obtain with these techniques for emittances in the few pm regime, there is evidence that a vertical emittance of the order of 5 pm has been achieved [3].

The new lattice design for the NLC Main Damping Rings is reported in [4]. The main motivation for the redesign was to raise the thresholds for some instabilities by raising the momentum compaction and lengthening the bunch. At the same time, an effort was made to reduce the sensitivity to the magnet misalignments, e.g. by moving the vertical tune closer to the half-integer. The longer bunch also has the effect of reducing the IBS emittance growth. The new lattice design has sufficient margin that IBS should not increase the emittance above the value specified for operation.

An updated version of Table 7.3 appearing in the ILC-TRC 2003 report on page 311 is given below. We see that the parameters specified for the NLC MDR place it in the same vertical emittance regime as the ATF and the ALS operating at their lowest achieved vertical emittances.

<table>
<thead>
<tr>
<th></th>
<th>ATF</th>
<th>ALS</th>
<th>NLC MDR</th>
<th>TESLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>1.3</td>
<td>1.9</td>
<td>1.98</td>
<td>5.0</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>140</td>
<td>197</td>
<td>300</td>
<td>17000</td>
</tr>
<tr>
<td>$\gamma\varepsilon_x$ [µm]</td>
<td>2.8</td>
<td>24</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>$\gamma\varepsilon_y$ [nm]</td>
<td>11</td>
<td>20</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>Sextupole Vertical Alignment Sensitivity [µm]</td>
<td>52</td>
<td>30</td>
<td>53</td>
<td>11</td>
</tr>
<tr>
<td>Quadrupole Roll Sensitivity [µrad]</td>
<td>873</td>
<td>205</td>
<td>511</td>
<td>38</td>
</tr>
<tr>
<td>Quadrupole Vertical Alignment Sensitivity [nm]</td>
<td>218</td>
<td>231</td>
<td>264</td>
<td>76</td>
</tr>
</tbody>
</table>

Note:
- For the ATF and ALS, the emittances given are the achieved values; for the NLC MDR, the emittances are the specified values.
- The sextupole vertical alignment sensitivity is defined as the rms random vertical misalignment, starting from a perfectly aligned lattice that will generate the vertical emittance given in the table.
- The quadrupole roll sensitivity is defined as the rms random quadrupole rotation about the beam axis, starting from a perfectly aligned lattice that will generate the vertical emittance given in the table.
- The quadrupole vertical alignment sensitivity is defined as the rms random quadrupole vertical misalignment, starting from a perfectly aligned lattice that will generate an orbit distortion equal to the vertical beam size at the stated vertical emittance.

**Expected R&D:**

Experimental studies at the ATF and ALS have shown that the vertical emittance specified for the NLC/GLC Main Damping Rings can be achieved with good reproducibility using more than one technique. Although additional studies may provide useful information, the experimental results are far more meaningful than any simulations, and we believe that the goal of demonstrating the tuning of a lattice to achieve a vertical emittance below 5 pm has been achieved.
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Studies will continue to optimize the ring dynamic aperture and characterize collective instabilities in the present designs for the NLC/GLC damping rings. At the ATF, studies for 2004 will focus on emittances with multi-bunch operation (including the fast ion instability – see R2 #4) and on the effect of the wiggler magnets.

References:


