BEAM TESTS OF A CLEARING ELECTRODE
FOR ELECTRON CLOUD MITIGATION
AT KEKB POSITRON RING

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1. Electron cloud issues

- The electron-cloud effect is one of the most important problems in recent high-intensity positron/proton storage rings.
  - The electron cloud excites single or multi-bunch beam instabilities and deteriorates the performance.

- Various types of techniques for mitigating this effect have been studied so far, such as
  - Beam pipe with antechamber(s)
  - Solenoid around a beam pipe
  - Coatings with a low secondary electron yield (SEY)
    - TiN, NEG materials, Graphite
  - Grooved surface
  - Clearing electrode

Here reported on R&D of the clearing electrode for positron rings.
2.1 Clearing electrode

- The clearing electrode in a beam pipe had been said to be an effective method to reduce the electron density around the beam by absorbing electrons through a static electric field.
- Especially, it is available in a magnetic field, unlike a solenoid for drift space.
- However, the heating and impedance problem have been precluding the use of electrodes to high-intensity positron rings ($\geq 1\text{mA/bunch}$), where the bunch length is relatively short ($\leq 1\text{ cm}$).

New electrode structure has been developed in KEK and tested with an intense positron beam.
2.2 Newly-developed clearing electrode

- Very thin electrode structure
  - 0.2 mm $\text{Al}_2\text{O}_3$ insulator and 0.1 mm tungsten (W) electrode formed by a thermal spray method.
  - High adhesion
    $\Rightarrow$ Good heat transfer and low beam impedance

- Flat connection between feed-through and electrode
  - Step $\leq 0.3$ mm except for a small hole on screw head.

Images:
- An insertion for test with a thin electrode
- Flat connection between feed-through and electrode
- Step $\leq 0.3$ mm except for a small hole on screw head.

References:
2.3 Merit of the thin electrode -1

- Dependence of loss factor and wake potential on the thickness of Al₂O₃ insulator
  - Calculated by using GdfidL (1m model, half chamber)
  - 0.2 mm ~ 2.0 mm (pipe: φ90mm)

With a decrease in the thickness of insulator, the loss factor decreases.
The wake potential also decreases, and is inductive for thin insulator.
2.3 Merit of the thin electrode -2

- Dependence of impedance on the thickness of Al$_2$O$_3$ insulator
  - $t$ 0.2 mm $\sim$ 2.0 mm

[Graph showing Longitudinal Impedance vs frequency for different Al$_2$O$_3$ thicknesses]

- Calculated for 20 m (for $\sigma_z$ = 20 mm).
- A periodic impedance is found as in the case of a usual strip line.
- The peak values become small with decreasing the thickness of insulator.
- The values are less than 1 $\Omega$. $Q \sim 20$.

- Relatively easily manufactured by using the thermal spray.
  - Open space above the surface is required.
3.1 Beam test in a wiggler magnet -1

- A test chamber was installed in a wiggler magnet. [2008]
  - Magnetic field: 0.78 T
  - Effective length: 346 mm
  - Aperture (height): 110 mm
  - Photons: $1 \times 10^{14}$ photons/s/m/mA

- An electron monitor and an insertion with an electrode are placed at the center of a pole, face to face.
- Electron monitor has an RFA and 7 strips to measure spatial electron distribution (~40 mm width in total).
3.1 Beam test in a wiggler magnet -2

- Electric potential in the test chamber
  - ~6 kV/m at the beam orbit, when 500 V is applied to the electrode.

- KEKB positron ring
  - Energy = 3.5 GeV
  - Beam current ~1.6 A with 1585 bunches (~1 mA [=10 nC] /bunch)
  - Typical bunch spacing ~ 6 ns (4 ~ 16 ns in study)
  - Bunch length ~ 6 mm at 1.6 A
3.2 Results -1

- Effect of electrode voltage ($V_{elec}$)
  - Drastic decrease in the electron currents by applying $V_{elec}$ was observed.

The electrons with an energy > 1 kV comes from near the beam
- The electron currents reflect the electron density around the beam.
- For negative $V_{elec}$, electrons flows into the monitor. Detailed simulation will be required to understand the complicated behavior of measured data.
3.2 Results -2

- Effect of electrode potential ($V_{\text{elec}}$)
  - Similar effect was observed for 4 ~ 16 ns spacing.

- The density greatly decreased by $V_{\text{elec}} \sim 300$ V.
- The electrode seems more effective for the bunch filling patterns with longer bunch spacing.
3.2 Results -3

- Comparison with a flat TiN-Coated surface
  - The electron density decreased to less than ~1/100 at $V_{\text{elec}} > \sim +300$ V compared to the values at $V_{\text{elec}} = 0$ V (W) and a TiN-coated flat surface.
  - Two-time experiments.
  - Electron currents for the thermal-sprayed tungsten ($V_{\text{elec}} = 0$V) is similar to the case of flat TiN-coated surface.
  - Rough surface?
  - No extra heating of electrode and feed-through was observed.
4.1 Application to a beam pipe with antechamber

- Final check of heating of electrode and feed through [2009]
  - Beam pipe with antechamber will be used for the wiggler section of Super KEKB.
- The beam pipe was installed at a magnetic-free region.
  - But the length was adjusted to fit the real wiggler magnet.
  - Length = 950 mm, width = 32 mm.
4.1 Application to a beam pipe with antechamber

- Electric potential in the beam pipe
  - ~3 kV/m at the beam orbit, when 500 V is applied to the electrode.

- Vertical field was applied by solenoids for test at the position of an electron monitor.
  - ~ 70 G at max.
4.2 Results -1

- Heating of electrodes
  - Temperature behind the electrode was measured.
  - No cooling channels in the back

- Estimated input power was ~40 W/m: reasonable value considering Joule loss and parasitic loss.
- No heating at feed through: < 30°
4.2 Results -2

- Effect of electrode voltage ($V_{elec}$) in magnetic-free condition
  - Electron density decreased with an increase in electrode voltage. But the reduction was much smaller than the case inside wiggler magnet.
  - The reduction became larger by applying a vertical field of $B \sim 60$G.
  - The reduction rate seems reasonable from a simulation:
    - Effective to electrons near the electrode for $B = 0$ G

![Graph showing electron density vs. $V_{elec}$ with and without magnetic field]
5. Impedance issues

- Influence estimation of the impedance on a storage beam has recently started assuming that the electrode is used for the wiggler section of Super KEKB.
  - The total length of the electrodes will be approximately 160 m (100 electrodes) out of 3016 m circumference.
- Preliminary result ($\sigma_z = 6 \text{ mm, } \phi = 90 \text{ mm}$)

<table>
<thead>
<tr>
<th>Total loss factor</th>
<th>O</th>
<th>$1.7 \times 10^{11} \text{ V/C} \ll 1.8 \times 10^{13} \text{ V/C}$ in total for one ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microwave instability</td>
<td>O</td>
<td>By simulation</td>
</tr>
<tr>
<td>Longitudinal coupled bunch instability</td>
<td>O</td>
<td>Total $R_s \leq 100 \Omega$, $R_s/Q = 0.1 \sim 1$&lt;br&gt;Growth rate $\sim 1 \text{ 1/s} &lt; 30 \text{ 1/s}$</td>
</tr>
<tr>
<td>Transverse coupled bunch instability</td>
<td>To be evaluated</td>
<td></td>
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<tr>
<td>Transverse mode coupling instability</td>
<td>O</td>
<td>Total kick factor $\sim 1.6 \times 10^{13} \text{ V/C/m}$.&lt;br&gt;Threshold bunch current $\sim 430 \text{ mA/bunch}$</td>
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</tbody>
</table>
8. Summary of clearing electrode

- The newly developed thin electrode structure works well even under an intense positron beam.
  - No heating of electrode and feed-through in the latest version.

- The effect on reducing the electron cloud is drastic in a strong magnetic field.
  - Much larger than other methods, such as coatings, grooved surfaces.
  - It worked even in a magnetic-free condition, but the effect was smaller than in the strong magnetic field. More studies are required in the future.

- The electrode seems to be available for the wiggler section in Super KEKB
  - The final beam test is ongoing.
  - The influence of impedance on the storage beams seems small.
  - Further detailed investigation will continue.