Low energy electron beam as a nondestructive diagnostic tool for high power beams.

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Electron beam probe for RF linacs.

- Beam structure monitoring.
- Wake-fields monitoring.
- Monitoring of the bunch tilt.
- Bunch-to-bunch position monitoring.
Electron Beam Probe

- basic idea
- scheme
- EBP at VEPP-5 injector linac

EBP is routinely used for tuning the beam at the VEPP-5 injector linac

longitudinal distribution of beam density, transverse position of its center of mass, even wake fields observation, single and multibunch regime
Single bunch regime

Offset parameter goes down->

Examples of signals from EBP

Collision with intense bunch
Single bunch regime: offset parameter goes down ->

Multi bunch regime: offset parameter goes down ->
Pictures with wakes

Two bunches
Wakes start to appear

Collision with single bunch
HFSS E-field plot

Probe beam

Bunch trajectory
$W_{pb} = 36 keV$

$E_{wake} = 0.05 * E_{bunch}$
\( W_{pb} = 36 keV \)

\[ E_{\text{wake}} = 0.05 \times E_{\text{bunch}}, \quad E_{\text{bunch}} = 50 \text{ kV/cm}. \]
Electron beam probe for circular collider.

- Bunch length measurement.
- Bunch position monitor.
- Measurement of bunch tilt.
Scheme of VEPP-4 electron beam probe.
Simulation for VEPP-4

Longitudinal bunch sigma - 4 cm, transverse bunch sigma - 0.001 см.

Ne = 7.6 \cdot 10^{9} \quad Ne = 14.2 \cdot 10^{9} \quad Ne = 22.8 \cdot 10^{9}

Screen size 2x2 cm.
Simulation results

Probe beam energy 30 keV, Transverse bunch sigma 0.001 cm.
Longitudinal bunch sigma (ps) dependence upon the vertical size of the image on the screen (cm).
## Experimental results from VEPP-4

<table>
<thead>
<tr>
<th>Image on the screen</th>
<th>Number of e- in the bunch</th>
<th>Vertical size of the loop</th>
<th>Bunch current duration</th>
<th>Bunch length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$7,6 \cdot 10^9$</td>
<td>$0.5 \text{ см}$</td>
<td>87.5 ps</td>
<td>2.6 см</td>
</tr>
<tr>
<td></td>
<td>$14,2 \cdot 10^9$</td>
<td>$0.8 \text{ см}$</td>
<td>110 ps</td>
<td>3.3 см</td>
</tr>
<tr>
<td></td>
<td>$22,8 \cdot 10^9$</td>
<td>$1.0 \text{ см}$</td>
<td>130 ps</td>
<td>3.9 см</td>
</tr>
</tbody>
</table>
Electron Beam Probe
for nondestructive diagnostics

of the ILC bunch tilt

for better control of the ILC beam emittance
Comparisons with simulations help to understand EBP signal

\[ \sigma_l = 6 \text{ mm} \quad Q^k = 0.1 \text{ mWm} \quad N_e = 3.0 \cdot 10^9 \quad W_{pb} = 50 \text{ keV} \]
Tilt in the ILC beam

will result in asymmetry
which is easy to measure or to minimize
EBP simulation assumptions for ILC

Pulsed current density in 200 kV electron gun is about 20 A/cm².

Collimating diaphragm diameter of 0.1 mm => about 2 mA of probe beam current.

It gives for 0.1 mm ILC bunch length (0.5 ps at v=0.7c) 6000 electrons in the close vicinity of ILC bunch.

These electrons will form the image (MCP operates in the single electron regime).

The probe beam envelope from the gun exit to the screen (horizontal axis (cm)), interaction point is placed 2 cm before the screen. The vertical axis gives the RMS transverse probe beam size in cm (probe beam is round).
EBP signal, ideal bunch, no "banana" distortion

The intensity asymmetry between upper left and down left branches of the loops reflects the displacement of the bunch tail.

Asymmetry in the right branches reflects the bunch head displacement.

The right down branch is more intense - it means the bunch head displaced up.

ILC bunch parameters: $\sigma_z = 0.1$ mm, $\sigma_y = 1$ $\mu$m, $\sigma_x = 20$ $\mu$m, $N = 0.7 \times 10^{10}$

EBP: 200 keV, pulsed, beam current 2 mA, diameter at the gun exit is 0.1 mm, probe beam diameter in the interaction region is about 0.05 mm. Each dot on the screen, which paced 2 cm after the interaction point, corresponds to single electron (about 6000 electrons in the vicinity of ILC bunch).
**EBP for ILC bunch tilt control**

This mode of operation was successfully tested at S-band linac of VEPP-5 injector complex for the bunch length of 4 mm and 0.5 mm transverse size

**Simulation for typical ILC bunch parameters**

<table>
<thead>
<tr>
<th>( \delta y ) = 1 ( \mu )m</th>
<th>( \delta y ) = 4 ( \mu )m</th>
<th>( \delta y ) = 8 ( \mu )m</th>
<th>( \delta y ) = 16 ( \mu )m</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Screen images for increasing amplitude of the bunch tilt ( \delta y )." /></td>
<td><img src="image2" alt="Screen images for increasing amplitude of the bunch tilt ( \delta y )." /></td>
<td><img src="image3" alt="Screen images for increasing amplitude of the bunch tilt ( \delta y )." /></td>
<td><img src="image4" alt="Screen images for increasing amplitude of the bunch tilt ( \delta y )." /></td>
</tr>
</tbody>
</table>

The bunch head is \( \delta y \) up at \( +\sigma_z \) and the tail is \( \delta y \) down at \( -\sigma_z \)

**The asymmetry monotonically increase with increase of beam tilt**

ILC bunch parameters: \( \sigma_z = 0.1 \) mm, \( \sigma_x = \sigma_y = 10 \) \( \mu \)m, \( N = 0.7 \times 10^{10} \)

EBP: 200 keV, pulsed 2 mA, probe beam diameter in the interaction region is about 0.05 mm. About 6000 electrons in the vicinity of ILC bunch.
EBP for ILC bunch tilt control

The image asymmetry dependence on the bunch tilting amplitude
The error bars show the statistical error
1/sqrt(Nparticles), Nparticles=5000

Measure of asymmetry:
\[ \Delta_1 = \frac{(N4-N1)}{(N4+N1)} \]
\[ \Delta_2 = \frac{(N2-N3)}{(N2+N3)} \]

In this example, the ILC single bunch tilting amplitude (or banana amplitude) can be measured starting from \( \sim 1 \) micron

ILC bunch parameters: \( \sigma_z = 0.1 \text{ mm}, \sigma_x = \sigma_y = 10 \mu\text{m}, N = 0.7 \times 10^{10} \)

EBP: 200 keV, pulsed 2 mA, probe beam diameter in the interaction region is about 0.05 mm. About 6000 electrons in the vicinity of ILC bunch.
Conclusion

The EBP based bunch tilt monitor appears to be a useful tool for ILC emittance control

Suggestions:
more simulation study
experimental test, e.g. at ATF
Electron beam probe as a profile monitor for intense proton beam.

- Beam profile scanning in 10 ns.
- Non destructing control during normal operation.
- Profile control on few different turns.
Layout of the proposed EBP for SNS accumulator ring

- Electron Gun
- Deflector
- Quadrupole lens
- MCP
- Proton beam
- Photocamera
- Phosphor screen
Simulation of the EBP

Probe beam:
Energy=75keV,
Scan.-parallel,
3rd, 4th quads - off

Proton beam:
OFF
Probe beam:
Energy=75keV, Scan.-parallel,
3\textsuperscript{rd}, 4\textsuperscript{th} quads - off

Proton beam:
Energy=1GeV
Np=1\times10^{13}
Transverse size r=1.5cm
Round uniform transverse distribution
Probe beam:
Energy=75keV,
Scan.-parallel,
3rd, 4th quads off

Proton beam:
Energy=1GeV
Np=$2\times10^{13}$
Transverse size $r=1.5\text{cm}$
Round uniform transverse distribution
Probe beam:
Energy=75keV,
Scan.-parallel,
3\textsuperscript{rd},4\textsuperscript{th} quads - off

Proton beam:
Energy=1GeV
Np=$5\times10^{13}$
Transverse size $r=1.5$cm
Round uniform transverse distribution
Probe beam:
Energy=75keV,
Scan.-parallel,
3rd, 4th quads - off

Proton beam:
Energy=1GeV
Np=1*10^{14}
Transverse size r=1.5cm
Round uniform transverse distribution
Proton beam profile reconstruction

Probe beam:
Energy=75keV,
Scan.-parallel,
3rd, 4th quads - off

Proton beam:
Energy=1GeV
Np=1*10^{13}
Transverse size r=1.5cm

Round uniform transverse charge distribution

Blue line – integrated beam profile under the test,
Magenta + square – reconstructed profile