CEPC Beam Instrumentation

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Outline

• CEPC beam instrumentation system
• Beam instrumentation R&D
• Summary
## The beam instrumentation in CEPC Linac

<table>
<thead>
<tr>
<th>Item</th>
<th>Method</th>
<th>Parameter</th>
<th>Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linac</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam position</td>
<td>Stripline BPM</td>
<td>Resolution: 30um</td>
<td>140</td>
</tr>
<tr>
<td>Beam current</td>
<td>ICT</td>
<td>2.5% @ 1nC-10nC</td>
<td>42</td>
</tr>
<tr>
<td>Beam profile</td>
<td>YAG/OTR</td>
<td>Resolution: 30um</td>
<td>80</td>
</tr>
<tr>
<td>Beam emittance</td>
<td>Q+PR</td>
<td>10%</td>
<td>3</td>
</tr>
<tr>
<td>Beam energy &amp; spread</td>
<td>AM+PR</td>
<td>0.1%</td>
<td>3</td>
</tr>
<tr>
<td><strong>Damping ring</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average current</td>
<td>DCCT</td>
<td>Resolution: 50uA @ 0.1mA-30mA</td>
<td>1</td>
</tr>
<tr>
<td>Beam position</td>
<td>Button BPM</td>
<td>Resolution: 20um @ 5mA TBT</td>
<td>40</td>
</tr>
<tr>
<td>Tune measurement</td>
<td>Frequency sweeping</td>
<td>Resolution: 0.001</td>
<td>1</td>
</tr>
<tr>
<td>Item</td>
<td>Method</td>
<td>Parameter</td>
<td>Amounts</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------</td>
<td>-----------------------------------------------</td>
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</tr>
</tbody>
</table>
| Beam position monitor| Turn by turn                | Measurement area \((x \times y)\) : ±20mm × ±10mm  
Resolution: <0.02mm  
Measurement time of COD: < 4 s | 1808    |
|                      | Bunch by bunch              | Measurement area \((x \times y)\) : ±40mm × ±20mm  
Resolution: 0.1mm |         |
| Bunch current        | BCM                         | Measurement range: 10mA / per bunch  
Relatively precision: 1/4095 | 2       |
| Average current      | DCCT                        | Dynamic measurement range: 0.0~1.5A  
Resolution:50uA @0.6-8mA  
Linearity: 0.1 %  
Zero drift: <0.05mA | 2       |
| Beam size            | Double slit interferometer  
 x ray pin hole          | Resolution:0.2 μm | 2       |
| Bunch length         | Streak camera               | Resolution:1 ps | 2       |
|                      | Two photon intensity        
 interferometer             |                                               |         |
| Tune measurement     | Frequency sweeping method   | Resolution:0.001 | 2       |
|                      | DDD                         | Resolution:0.001 |         |
| Beam loss monitor    | optical fiber               | Space resolution:0.6m | 400     |
| Feedback system      | TFB                         | Damping time<=3ms | 2       |
| Feedback system      | LFB                         | Damping time<=35ms (50ms) | 2       |
# The beam instrumentation in CEPC ring

<table>
<thead>
<tr>
<th>Item</th>
<th>Method</th>
<th>Parameter</th>
<th>Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storage ring</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam position monitor</td>
<td>Closed orbit</td>
<td>Button electrode BPM</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement area ((x \times y)): (\pm 20\text{mm} \times \pm 10\text{mm})</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resolution: &lt;0.6\text{um}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement time of COD: &lt; 4 s</td>
<td></td>
</tr>
<tr>
<td>Bunch by bunch</td>
<td>Button electrode BPM</td>
<td>Measurement area ((x \times y)): (\pm 40\text{mm} \times \pm 20\text{mm})</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resolution: 0.1\text{mm}</td>
<td></td>
</tr>
<tr>
<td>Bunch current</td>
<td>BCM</td>
<td>Measurement range: 10mA / per bunch</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relatively precision: 1/4095</td>
<td></td>
</tr>
<tr>
<td>Average current</td>
<td>DCCT</td>
<td>Dynamic measurement range: 0.0~1.5A</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linearity: 0.1 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zero drift: &lt;0.05mA</td>
<td></td>
</tr>
<tr>
<td>Beam size</td>
<td>Double slit interferometer x ray pin hole</td>
<td>Resolution: 0.2 \text{µm}</td>
<td>4</td>
</tr>
<tr>
<td>Bunch length</td>
<td>Streak camera Two photon intensity interferometer</td>
<td>Resolution: 1ps@10ps</td>
<td>2</td>
</tr>
<tr>
<td>Tune measurement</td>
<td>Frequency sweeping method</td>
<td>Resolution: 0.001</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>DDD</td>
<td>Resolution: 0.001</td>
<td></td>
</tr>
<tr>
<td>Beam loss monitor</td>
<td>PIN-diode</td>
<td>Dynamic range: 120 dB</td>
<td>5800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum counting rates(\geq 10\text{MHz})</td>
<td></td>
</tr>
<tr>
<td>Feedback system</td>
<td>TFB</td>
<td>Damping time(\leq 47\text{ms})</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>LFB</td>
<td>Damping time(\leq 100\text{ms})</td>
<td>2</td>
</tr>
</tbody>
</table>
Refine of CDR design

- Beam position monitor
- Beam current monitor
- Tune measurement
- The beam instrumentation of IP
To provide the beam position and orbit
To calculate machine parameters related to beam position
Apart from specific BPMs, there are 4708 BPMs in booster and storage ring.
Button type electrode with 8mm diameter will be adopted, for its good high frequency response and small beam impedance
The resolution of BPM will be ~2um
BPM pick-ups simulation

- Volts getting on the pickup is more than 100V when button diameter is 8mm
- Sensitivity be simulated at the different angle

- RF Beam position monitor
- In-house developed BPM electronics
- The BPM pick-ups are designed based CEPC beam parameters
Beam current monitor

- Including DCCT (for average current) and BCM (bunch current monitor)
- Using Bergoz-type DCCT to measure the average current of the beam and to calculate the life time of beam. The resolution will be µA level;
Beam current monitor

- Bunch current monitor with fast ADC sampling BPM sum signal is used to measure bunch current and share data with injection control system for bucket selection.

- The fast ADC is a commercial product. Innovative Integration XG-12. 2 channels 12-bits ADC with 1G sampling rate. 512MBytes DDR2 DRAM and PCI Express x8 sockets for data transmission.
**Tune measurement system**

- Frequency sweeping method with gated pulse or FFT analyzing to the data from the digital BPM.
- The BPM monitor, signal processing unit and the kicker form the entire system.
- Direct Diode Detection（3D）is another choice for tune monitor.
The beam instrumentation of IP

4 button electrodes structure

Electrode diameter: 11.4mm
Inner conductor diameter: 6mm
Electrode pole to beam line: 19.4mm

Electromagnetic field at electrodes

Electrodes signal (bunch length 2.68mm)

Size and signal intensity can be satisfied by CEPC MDI requirement.

Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.
The beam instrumentation of IP

- Space conflict for the inside two buttons has been solved by staggering the position ~1cm.
- Monitoring the time when two beams arrive at the collision point, e+ and e- signals can be distinguished.
R&D Motivation

• To reduce the budget of BI system, due to a large number of monitors and the high price of commercial products. Such as BPM
• Key technologies of beam diagnostics.
• Easy to maintain and upgrade
CEPC beam instrumentation R&D

- Beam position monitor system
  - BPM electronics
  - Feed through R&D
- Feedback systems
Overview of the BPM electronics R&D

• The R&D of BPM electronics founded by seed money of IHEP and other funding (HEPS-TF etc.)
• Kicked off in the start of 2015
• The first version (V1.0) of the electronics was finished in 2018.
• The second version (V2.0) was finished in middle of 2019. Modification was done to improve the performance of the electronics.
• The BPM electronics were installed and operating in BEPCII Linac in 2019
• BEPCII SR BPMS were upgrade to home-made electronics last year.
The front-end electronics of BPM

- Eight editions of electronics have been developed to improve the performance in the past four years.
- Finally, the front-end electronics cross talk is better than -70dB and the dynamic range is 60dB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Range</td>
<td>60dB</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 10 dB</td>
</tr>
<tr>
<td>Input power</td>
<td>-60 to 0 dBm</td>
</tr>
<tr>
<td>Central frequency</td>
<td>499.8MHz</td>
</tr>
<tr>
<td>Cross talk</td>
<td>&lt; -40 dB</td>
</tr>
<tr>
<td>Bandwidth (3dB)</td>
<td>30 MHz</td>
</tr>
<tr>
<td>1dB Compression Point</td>
<td>&gt; 20 dBm</td>
</tr>
<tr>
<td>Long term stability</td>
<td>&lt; 0.01 dB</td>
</tr>
</tbody>
</table>
BPM electronics version 1.0

- ADC chips were placed in Back-end module
- The clock logic was located in the Back-end module, same with the ADC logic.
- RF signal transfer from front-end module to back-end one with the ADF connector.
BPM electronics version 2.0
BPM TbT/FA/SA Resolution Test in Lab

- We test the performance of DBPM in house.
- RF frequency is 499.8MHz(-15dBm) from R&S SMA100.
- TBT data rms xpos \( \approx 767\)nm, ypos \( \approx 786\)nm.
- FA data rms xpos \( \approx 103\)nm, ypos \( \approx 98\)nm.
- SA data rms xpos \( \approx 30\)nm, ypos \( \approx 38\)nm.
- Kx=Ky=8.26mm.
Application of BPM electronics in BEPCII

- After finishing prototype test, small batch production and application has been done in BEPCII.
- Last year, a part of BEPCII SR BPM electronics were upgraded to home-made style. The rest will be done this year.
- The single-pass mode BPM electronics is developed for the linac and put in operation in the middle of 2019.
The beam trip is an important problem for accelerator operation. Because the accelerator system is very complicated, involves many subsystems, and various conditions are mixed together, so, it is difficult to get to the real cause for beam trip.

At present, many accelerators all over the world have established a powerful beam trip diagnostic system.

Beam trip seriously affects the efficiency of the machine, also may cause damage to the hardware system. So, it is necessary for CEPC to develop bunch by bunch BPM for studying the beam trip.
Buffer of bunch by bunch raw ADC data
Bunch by bunch BPM electronics

Sampling clock: 500MHz, free running clock or externally clock locked with beam signal
Bunch by bunch BPM electronics

Input: simulation pattern of BEPCII, repetition period 6ns
Feed-through R&D

- Finished the study of feed-through in beam instrumentation.
- Independent research and development of feed-through was kicked off.
- Two versions of feed-through have been made with the help of CIPC Member Company in the last year.

BPM feed-through V1.0  BPM feed-through V2.0  Kicker feed-through
Feed-through R&D

• The test result of the feedthroughs shows that the mechanical properties, high-frequency characteristics and vacuum performance can meet the demands of the CEPC BPM totally.

• TDR for impedance test and X-ray tomography for inner structure check.
Feed-through R&D

• Morphology of solid surface by SEM
Summary

- Based on the CDR, subsystems such as beam position monitor, beam current monitor and feedback are refined.
- The beam position monitor and other key technologies R&D has been carried out.
- Many modifications have been made in BPM electronics to improve the performance. Small batch production have been used online in BEPCII linac and storage ring.
- The bunch by bunch system was developed for CEPC beam diagnostics. More test will be done with real beam in BEPCII.
- More attention will be paid in the beam feedback and beam instrumentation in interaction point(IP).
Thanks for your attention!