BEAM DYNAMICS OF CHINA
ADS DRIVER LINAC

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On behalf of IHEP-IMP Joint Accelerator Physics Group
of C-ADS

Institute of High Energy Physics, CAS
C-ADS Project is ……

- A strategic plan to solve the nuclear waste problem for nuclear power plants in China;
- Study scientific problems and developing techniques associated with ADS;
- Three parts: accelerator, target and reactor;
- Goals: demonstration facility for wastes transmutation with capacity of 1GW thermal power;
# Key Parameters of C-ADS Linac

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1.5 GeV</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>10 mA</td>
<td></td>
</tr>
<tr>
<td>Beam power</td>
<td>15 MW</td>
<td></td>
</tr>
<tr>
<td>RF frequency</td>
<td>(162.5)/325/650 MHz</td>
<td>MHz</td>
</tr>
<tr>
<td>Duty factor</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>Beam Loss</td>
<td>&lt;1 W/m</td>
<td></td>
</tr>
<tr>
<td>Beam trips/year</td>
<td>&lt;25000 &lt;2500 &lt;25</td>
<td>1s&lt; t &lt;10s 10s&lt; t &lt;5m t &gt;5m</td>
</tr>
</tbody>
</table>
Characteristics of C-ADS linac

- High power
  - Beam loss rate: $<10^{-8}$
  - Dynamics: match, halo, resonance

- High availability
  - Potential “show stopper”
  - Fault tolerance and redundancy design

- CW
  - Cavity type
- Parallel backup (< 10 MeV)
- Local compensation (> 10 MeV)
- 30% field is reserved for compensation
  - Longitudinal match
  - Energy match
  - Phase match

Local compensation is applicable for energy greater than 10 MeV
Lattice Structure

Period lattice:
  easy for compensation;
  robust in beam dynamics;

For match

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Triplet like quadrupoles are applied in elliptical sections;
Cavities

- $E_{\text{max}} < 32.5 \text{MV/m}$ for 325MHz cavity
- $E_{\text{max}} < 39 \text{ MV/m}$ for 650MHz cavity
- $B_{\text{max}} < 65 \text{ mT}$
- 3 types of Single spoke cavity / 1 type HWR and two types of single spoke
- 2 types of 5-cell elliptical cavity

<table>
<thead>
<tr>
<th>Cavity type</th>
<th>$\beta_g$</th>
<th>Freq. MHz</th>
<th>Uacc. Max MV</th>
<th>$E_{\text{max}}$ MV/m</th>
<th>$B_{\text{max}}$ mT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWR</td>
<td>0.09</td>
<td>162.5</td>
<td></td>
<td>25.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Single-cell spoke</td>
<td>0.12</td>
<td>325</td>
<td>0.82</td>
<td>32.5</td>
<td>47.5</td>
</tr>
<tr>
<td>Single-cell spoke</td>
<td>0.21</td>
<td>325</td>
<td>1.64</td>
<td>23.95/31.14</td>
<td>50/65</td>
</tr>
<tr>
<td>Single-cell spoke</td>
<td>0.40</td>
<td>325</td>
<td>2.86</td>
<td>24.66/32.06</td>
<td>50/65</td>
</tr>
<tr>
<td>5-cell elliptical</td>
<td>0.63</td>
<td>650</td>
<td>10.26</td>
<td>29.01/37.72</td>
<td>50/65</td>
</tr>
<tr>
<td>5-cell elliptical</td>
<td>0.82</td>
<td>650</td>
<td>15.63</td>
<td>27.53/35.80</td>
<td>50/65</td>
</tr>
</tbody>
</table>

1/3 capability is reserved for local compensation
Failures investigated:

- Cavity failure;
- Solenoid failure;
- Quadrupole;

Goals:

- Twiss match;
- Energy;
- Beam quality;

Cavity and quadrupole failures are easy to compensate, the mismatch factor after compensation is only about 1%, and RMS and 100% particle emittance growth nearly no significant change;

Solenoid failure is the most difficult to compensate, and special measures have to be taken.
Mismatch factor in transverse: 10%
RMS emittance growth: 7%
Design Criteria

- $\sigma_0 < 90^\circ$ for both longitudinal and transverse planes;
  - Space charge is not negligible: $\sigma/\sigma_0 \approx 0.7$
  - Parametric resonance: $L_{\text{eff}} < L_{\text{period}}$ at low energy part
- The external force is smooth and continues;
- Special care has to be taken to avoid the parametric resonance as well as space charge resonance;
  - Emittance exchange-Hofmann Chart
- Enough acceptance:
  - $|\text{Synch. Ph.}| / |\text{RMS Ph. width}| > 10$
  - $(\text{Half aperture})/(\text{RMS envelop}) > 10$
<table>
<thead>
<tr>
<th>Elements</th>
<th>Solenoid</th>
<th>Spoke cavity</th>
<th>Elliptical cavity</th>
<th>Quadrupole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alignment / Field error</td>
<td>Alignment / RF error</td>
<td>Alignment / RF error</td>
<td>Alignment / Field error</td>
</tr>
<tr>
<td>Δx (mm)</td>
<td>±1</td>
<td>±1</td>
<td>±1</td>
<td>±0.2</td>
</tr>
<tr>
<td>Δy (mm)</td>
<td>±1</td>
<td>±1</td>
<td>±1</td>
<td>±0.2</td>
</tr>
<tr>
<td>Δz (mm)</td>
<td>±1</td>
<td>±1</td>
<td>±1</td>
<td>±0.5</td>
</tr>
<tr>
<td>φx (mrad)</td>
<td>±2</td>
<td>±2</td>
<td>±2</td>
<td>±2</td>
</tr>
<tr>
<td>φy (mrad)</td>
<td>±2</td>
<td>±2</td>
<td>±2</td>
<td>±2</td>
</tr>
<tr>
<td>φz (mrad)</td>
<td>---</td>
<td>--- ±2</td>
<td>---</td>
<td>±2</td>
</tr>
<tr>
<td>ΔE(%)/ΔB(%)</td>
<td>±0.5</td>
<td>±1</td>
<td>±1</td>
<td>±0.5</td>
</tr>
<tr>
<td>φRF (°)</td>
<td>---</td>
<td>±1</td>
<td>±1</td>
<td>---</td>
</tr>
<tr>
<td>BPM accuracy</td>
<td></td>
<td></td>
<td>±0.1 mm</td>
<td></td>
</tr>
</tbody>
</table>
Injector I

- Low inter-vane voltage and input energy
- Low longitudinal emittance

**RFQ**
- Space: diagnostic devices
- Buncher: normal conducting and high effective voltage ~120kV

**MEBT1**
- Low energy, large phase width -> $\sigma_0 < 90$ degree
- Compact lattice structure -> fine segmentation

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# Injector I

## Parameters of cavities

<table>
<thead>
<tr>
<th>Cavity #</th>
<th>phase</th>
<th>Field level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-43</td>
<td>0.92</td>
</tr>
<tr>
<td>2</td>
<td>-40</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>-38</td>
<td>1.08</td>
</tr>
<tr>
<td>4</td>
<td>-36</td>
<td>1.16</td>
</tr>
<tr>
<td>5</td>
<td>-34</td>
<td>1.21</td>
</tr>
<tr>
<td>6</td>
<td>-32</td>
<td>1.27</td>
</tr>
<tr>
<td>7</td>
<td>-30</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>-30</td>
<td>1.3</td>
</tr>
<tr>
<td>9</td>
<td>-30</td>
<td>1.3</td>
</tr>
<tr>
<td>10</td>
<td>-30</td>
<td>1.3</td>
</tr>
<tr>
<td>11</td>
<td>-30</td>
<td>1.3</td>
</tr>
<tr>
<td>12</td>
<td>-30</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Injector I

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Proportion of particles

<table>
<thead>
<tr>
<th>Proportion</th>
<th>0.95</th>
<th>0.99</th>
<th>0.999</th>
<th>0.9999</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emittance growth(%)</td>
<td>23.7</td>
<td>14.9</td>
<td>12.6</td>
<td>20.5</td>
<td>413</td>
</tr>
</tbody>
</table>
Main Linac

F. Yan et al., MOP221

- Two types of design corresponding to the two Injector schemes:
  - Injector I : \((E_z, E_t) = (0.21, 0.25)\)
  - Injector II: \((E_z, E_t) = (0.37, 0.32)\)

- Solutions:
  - Apply the design corresponding to Injector I to two schemes of Injectors;
  - Totally new design by apply some HWR cavities at the beginning of the main linac;
Main linac

F. Yan et al., MOP221

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MEBT2

- **injector**
- **Main linac**

- Length: about 4 m for the bending section;
- Low energy: space charge effect;
- Buncher outside the bending section: phase width is hard to control;
End to End Simulation

- RMS Emittance growth
  - 15% in transverse;
  - 40% in longitudinal;
- Halo particles
- Particle loss with errors;

MEBT2 and Input distribution!

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Thank you for your attention!
Backup slides
Implementation of the Criteria

Section design

\[ \sigma_0 < 90, \sigma_{i_0}/\sigma_{i_0} = \varepsilon_i/\varepsilon_i \]

Phase for acceptance

Envelop smooth, emittance growth

Linac design

\[ \sigma_0/1 \text{ smooth and continues} \]

Match between sections

\[ \sigma_{0i, end}/1, \text{period} = \sigma_{0i+, start}/1_{i+1}, \text{period} \]

Envelop and emittance

Error analysis

Error settings

Front to end simulation

Envelop and emittance

Particle loss

Match

Smooth focusing strength

Error settings

Correction schemes

Design check

Period length

Synchronous phase

Field level

Transverse focusing

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