CEPC RF Sources System

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Institute of High Energy Physics
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Contents

- Design proposal
- R&D Progress
- Summary
Design proposal
Future large accelerators

FCCee, CW, 800MHz, Prf=110MW

ILC, Pulse, 1.3GHz, Prf=88MW

CLIC, Pulse, 1.0GHz, Prf=180MW
Future large accelerators

CEPC-SppC, CW, 650MHz, Prf=100MW
Current situation

For future large accelerators, just like ILC, FCC and CEPC. It’s beam power is very high, so high efficiency RF source is much more important.

<table>
<thead>
<tr>
<th></th>
<th>Tetrodes</th>
<th>IOTs</th>
<th>Conventional klystrons</th>
<th>Solid State PA</th>
<th>Magnetrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$ range:</td>
<td>DC – 400 MHz</td>
<td>(200 – 1500) MHz</td>
<td>300 MHz – 1 GHz</td>
<td>DC – 20 GHz</td>
<td>GHz range</td>
</tr>
<tr>
<td>$P$ class (CW):</td>
<td>1 MW</td>
<td>1.2 MW</td>
<td>1.5 MW</td>
<td>1 kW @ low $f$</td>
<td>&lt; 1MW</td>
</tr>
<tr>
<td>typical $\eta$:</td>
<td>85% - 90% (class C)</td>
<td>70%</td>
<td>50%</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>Remark</td>
<td></td>
<td></td>
<td></td>
<td>Requires $P$ combination of thousands!</td>
<td>Oscillator, not amplifier!</td>
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Remark

RF sources for accelerator are IOT, klystron and solid state amplifier. From cost, frequency limitation and power level, klystron is still the first choice.
Current situation

• 2014 saw a breakthrough in klystron theory:
  – 1981, “congregated bunch” was re-introduced [V.A. Kochetova, 1981] (later electrons faster when entering the output cavity).
  – 2013, BAC method was invented[I.A. Guzilov, O.Yu. Maslennikov, A.V. Konnov, “A way to increase the efficiency of klystrons”, IVEC 2013] (Bunch, Align velocities, Collect outsiders)

• These method together promise a significant increase in klystron efficiency(approaching 90%)

• A international collaboration has started. HEIKA – “High Efficiency International Klystron Activity” is evaluating and implementing this “breakthrough”.
CEPC Collider RF sources

Baseline

Considering klystron lifetime and power redundancy, 2 cavities will be powered with a CW klystron capable to deliver more than 800 kW.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Operation frequency</td>
<td>650MHz±0.5MHz</td>
</tr>
<tr>
<td>RF input power (kW)</td>
<td>280 CW (250)</td>
</tr>
<tr>
<td>RF source number</td>
<td>160</td>
</tr>
<tr>
<td>Klystron output power (kW)</td>
<td>800 CW</td>
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</table>

1 klystron power 2 cavities
# CEPC Collider RF sources

## Klystron key design parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Now</th>
<th>Future</th>
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<tr>
<td>Centre frequency (MHz)</td>
<td>650 +/- 0.5</td>
<td>650 +/- 0.5</td>
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<tr>
<td>Output power (kW)</td>
<td>800</td>
<td>800</td>
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<tr>
<td>Beam voltage (kV)</td>
<td>80</td>
<td>70</td>
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<td>Beam current (A)</td>
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<td>15</td>
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<td>Efficiency (%)</td>
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## CEPC Collider RF sources

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**How to do?**
# CEPC Collider RF sources

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*How to do?*

*There are some R&D work supported by IHEP innovation funds.*
R&D Progress
Klystron Schedule and strategy

Because of klystron efficiency is more than 80%, in order to fulfill this program, there may have following problems:

1) **No experience and no related infrastructure on this kind of klystron;**
2) **Design and simulation are not enough and matured;**
3) **Let’s start from beam tester, classical design and currently progressed design(higher efficiency design).**
Klystron Schedule and strategy(2)

(1) Beam tester
(2) #1 prototype
(3) #2 prototype

Merits
• Saving the money
• Saving the time
• Possible to try 2 or 3 designs
**R&D-Electron gun**

**EGUN simulation result:**
- Area compression ratio: 4.4
- Perveance: 0.647μP
- Cathode current density: 0.39A/cm²~0.43A/cm²
- Max. electric field: 2.520kV/mm

**Graphs:**
- Gun region beam trajectory simulation with Egun
- Electrode field density optimization with Possion
**R&D-Electron gun**

**DGUN simulation results**

DGUN simulation result:
- Beam Diameter=17.8mm
- Current=15.12 A
- Perveance= $1.43 \mu A/V^{3/2}$

- $V_c = -81.5$ kV
- $V_{MA} = -48.0$ kV

- Electric field strengths:
  - 2.51 kV/mm on M.Anode
  - 3.94 kV/mm on BFE
  - 1.77 kV/mm on Anode
  - 3.94 kV/mm on Anode

Graph showing Current Density vs. Cathode R(mm) from 5 to 35 mm.
**R&D - Electron gun**

*CST simulation results*

- Beam Diameter = 17.7 mm
- Current = 14.88 A
- Perveance = 1.41 μA/V^{3/2}
R&D-Electron gun

Simulation results comparison

\[ V_c = -81.5\text{kV}, \ V_{MA} = -48.0\text{kV} \]

<table>
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<tr>
<th>Type</th>
<th>DGUN</th>
<th>EGUN</th>
<th>CST</th>
</tr>
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<tbody>
<tr>
<td>Current (A)</td>
<td>15.12</td>
<td>14.88</td>
<td>14.88</td>
</tr>
<tr>
<td>Beam DIA (mm)</td>
<td>17.8</td>
<td>17.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Perveance (μA/V^{3/2})</td>
<td>1.43</td>
<td>1.41</td>
<td>1.41</td>
</tr>
</tbody>
</table>
R&D - Electron gun

Simulation results comparison

Amplitude of magnetic field Bz on axis
R&D-Beam trajectory

Ripple rate = 8.0%
R&D-Beam trajectory

Beam Tester without Magnetic Field

Beam Tester with Magnetic Field
**R&D-Beam trajectory**

**Solenoid**

**Gun assembly with Drift Tube and Collector**
R&D-Electron gun

HV Gun Envelop for Electron Gun
R&D-RF interaction

5 fundamental cavities and 1 2\textsuperscript{nd} harmonic cavity, 1 d simulation result shows 74.55% efficiency.
**R&D-RF interaction**

8 cavities and BAC method, 1 d simulation result shows 79.41% efficiency.
8 cavities, BAC method and low pervence gun, 1 d simulation result shows 85% efficiency.
R&D-RF interaction

We are doing more simulations in detail using other 2d and 3d codes. The final parameters of cavities will be given and then start to mechanical design with company engineers.
**R&D-Output window**

- Simulation and optimization
- Window and coupler cooling system design
- Window multipactor effector analysis
- Window coupler simulation and mechanical design
- High power test stand construction
R&D-Output window

multipactor effector simulation

99.5% Al2O3 and OFC multipactor effector

CST and MULTIPACT code simulation results
R&D-Output window

Structure optimization

With 800kW power and 650MHz frequency, S parameters and VSWR meet demands.
HFSS and CST electromagnet filed and thermal simulations

**R&D-Output window**

HFSS and CST simulations are in complete agreement.

**Electromagnet filed simulation**

**Thermal analysis simulation**

HFSS and CST simulations are in complete agreement.
**Collector shape and beam dissipation optimization**

**Collector**

<table>
<thead>
<tr>
<th>Collector Length</th>
<th>Analytic design</th>
<th>Numerical design</th>
</tr>
</thead>
<tbody>
<tr>
<td>2147mm</td>
<td>2112mm</td>
<td></td>
</tr>
</tbody>
</table>

**Collector radius**

<table>
<thead>
<tr>
<th>Collector radius</th>
<th>Analytic design</th>
<th>Numerical design</th>
</tr>
</thead>
<tbody>
<tr>
<td>210mm</td>
<td>210mm</td>
<td></td>
</tr>
</tbody>
</table>

**Total Beam power**

<table>
<thead>
<tr>
<th>Total Beam power</th>
<th>Analytic design</th>
<th>Numerical design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1231kW</td>
<td>1230kW</td>
<td></td>
</tr>
</tbody>
</table>

**Capability of power density in collector**

<table>
<thead>
<tr>
<th>Capability of power density in collector</th>
<th>Analytic design</th>
<th>Numerical design</th>
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<tbody>
<tr>
<td>150W/cm²</td>
<td>150W/cm²</td>
<td></td>
</tr>
</tbody>
</table>

**Max power density in collector**

<table>
<thead>
<tr>
<th>Max power density in collector</th>
<th>Analytic design</th>
<th>Numerical design</th>
</tr>
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<tbody>
<tr>
<td>197W/cm²</td>
<td>207W/cm²</td>
<td></td>
</tr>
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</table>
R&D-Collector

Groove dimensions optimization

<table>
<thead>
<tr>
<th>Groove number</th>
<th>Groove dimensions (a:b)</th>
<th>Total water flow rate</th>
<th>Water pressure loss for ideal smooth surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>1:2</td>
<td>1400kg/min</td>
<td>2.34E+4 Pa</td>
</tr>
</tbody>
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Contour of temperature and water pressure loss
R&D-Collector
Collector Thermal analysis

Groove structure for 2 meter tapered collector in Ansys-CFX

contour of temperature on inner surface of copper domain

contour of temperature of water domain
R&D-Collector

Collector geometry of tapered part

Geometry of collector tapered part

<table>
<thead>
<tr>
<th>Section</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tbody>
<tr>
<td>groove number</td>
<td>180</td>
<td>150</td>
<td>120</td>
<td>60</td>
<td>40</td>
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R&D-Collector

Final design
R&D-Beam tester

IHEP is taking bids now.
R&D-Current status

We form a joint institute with local government and Company: GLVAC Industrial Technology Research Institute of High Power Devices.
Summary

- The design of the electron gun and collector has been completed;
- RF Section for classical design klystron is completed;
- Mechanical design for beam tester is also completed;
- IHEP is taking bids for fabrication of beam tester;
- Mechanical design for classical design klystron is about to begin.
- RF Section for high efficiency design klystron is almost completed.
- Fabrication for high efficiency klystron will be discussed.
Thanks for your attention!