Development of Room Temperature and Superconducting CH-Structures for High Power Applications

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Overview

- H-mode cavities – CH-structure
- room temperature (rt) CH-structure (FAIR p-linac)
- superconducting (sc) CH-structure
- Projects (EUROTTRANS, IFMIF)
The Family of H-mode cavities ($H_{11}$, $H_{21}$)

<table>
<thead>
<tr>
<th>Low and Medium - $\beta$ Structures in H-Mode Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{110}$</td>
</tr>
<tr>
<td>$f \leq 100$ MHz</td>
</tr>
<tr>
<td>$\beta \leq 0.03$</td>
</tr>
<tr>
<td>$H_{210}$</td>
</tr>
<tr>
<td>$100 - 400$ MHz</td>
</tr>
<tr>
<td>$\beta \leq 0.12$</td>
</tr>
</tbody>
</table>

$H_{11} (0)$

$f \leq 300$ MHz

$\beta \leq 0.3$

$H_{21} (0)$

$150 - 800$ MHz

$\beta \leq 0.5$

Interdigital H-Mode (IH)

Crossbar H-Mode (CH)
The **CH**-Structure

**Cross-Bar H**-Mode-Structure

- High efficiency (Z) for low and medium energies (3-100 AMeV)
- Homogeneous distribution of losses → Good cooling possibilities
- Possible cw operation
- Use of KONUS → Less rf defocusing → long lensfree sections
- High real estate gradients
- High mechanical stability
- **Room temperature-** and **superconducting** operation
H-mode DTL-cavities

<table>
<thead>
<tr>
<th>rt IH</th>
<th>rt CH</th>
<th>sc CH</th>
</tr>
</thead>
<tbody>
<tr>
<td>E&lt; 30 AMeV</td>
<td>E&lt; 100 AMeV</td>
<td>E&lt; 100 AMeV</td>
</tr>
<tr>
<td>30&lt;f&lt;250 MHz</td>
<td>150&lt;f&lt;700 MHz</td>
<td>150&lt;f&lt;700 MHz</td>
</tr>
</tbody>
</table>
FAIR: Facility for Antiproton and Ion Research

GSI Today

Requirement: $7 \times 10^{12}$ p/pulse
UNILAC: Factor 500 too low

→ New dedicated p-injector

FAIR

$7 \cdot 10^{10}$ cooled $\bar{p}$ / hour

$2 \cdot 10^{16}$ p / hour
FAIR proton-linac

![Diagram of FAIR proton-linac]

- **Source**: LEBT
- **Re-Buncher**: RFQ
- **Energy**: 95 keV, 3 MeV, 70 MeV
- **To**: SIS18, Dump

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>Protons</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>70</td>
</tr>
<tr>
<td>Energy (MeV)</td>
<td>70</td>
</tr>
<tr>
<td>Frequency (MHz)</td>
<td>325.224</td>
</tr>
<tr>
<td>RF structures (6x)</td>
<td>r.t. CCH</td>
</tr>
<tr>
<td>Linac length (m)</td>
<td>25</td>
</tr>
<tr>
<td>RF drivers (6x)</td>
<td>2.5 MW Klystrons</td>
</tr>
<tr>
<td>Pulse power (MW)</td>
<td>4.9</td>
</tr>
<tr>
<td>Beam pulse length (μs)</td>
<td>36</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>4</td>
</tr>
</tbody>
</table>

High gradients (3-7 MV/m), low duty cycle → r.t. CH-structures
The Coupled CH (CCH)

Coupling of two CH-sections ($H_{21}$-mode) via a resonant oscillating coupling cell ($E_{010}$-mode)
The 2 kW level (4kW/m, ~ 310 kV) has been reached within 20 minutes

Measured $Q_0$: 13000 (95 % Ideal MWS Value)
Motivation for the Development of the Superconducting CH-Structure

Several fixed velocity accelerators with cw operation are under discussion (i.e. Spallation neutron sources, IFMIF, Transmuter, isotope production...)

- Superconducting operation

- lack of efficient superconducting low $\beta$ cavities, whereas efficient means large energy gain per cavity
Superconducting CH-Prototype

The first low energy s.c. multi cell cavity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap number</td>
<td>19</td>
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<tr>
<td>Length (mm)</td>
<td>1048</td>
</tr>
<tr>
<td>Frequency (MHz)</td>
<td>350</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.1</td>
</tr>
<tr>
<td>$E_p/E_a$ ($\beta\lambda$-definition)</td>
<td>5.2</td>
</tr>
<tr>
<td>$B_p/E_a$ (mT/(MV/m))</td>
<td>5.7</td>
</tr>
<tr>
<td>$G=R_s Q_0$ ($\Omega$)</td>
<td>56</td>
</tr>
<tr>
<td>$R_a/Q$ ($\Omega$) (T incl.)</td>
<td>3180</td>
</tr>
<tr>
<td>$(R_a/Q)G$ ($\Omega^2$)</td>
<td>178000</td>
</tr>
<tr>
<td>$Q_0$ (BCS, 4.4K, 352 MHz)</td>
<td>$1.5 \times 10^9$</td>
</tr>
<tr>
<td>$W$ (mJ/(MV/m)^2)</td>
<td>155</td>
</tr>
</tbody>
</table>
Cryogenic Test of the sc CH-cavity

\[ \sqrt{P_f} = \sqrt{P_{on}} \quad \sqrt{P_r} = \sqrt{P_{off}} \quad \sqrt{P_e} = \sqrt{P_{off}} \]
\[ L = n/2\beta\lambda = 9.5\beta\lambda \]

**Q_0 versus Gradient and Voltage**

- **Gradient**

\[ Q_0 \] versus \( E_{\text{acc}} \) (MV/m)

- **Voltage**

\[ Q_0 \] versus \( U_{\text{acc}} \) (MV)
Projects and possible applications (sc CH)

EUROTRANS (Nuclear waste transmutation)
IFMIF (Fusion material research)
A CH-Injector for XADS/EUROTRANS

LEBT MEBT Cryo-module

RFQ r.t. CH s.c. CH s.c. CH s.c. CH s.c. CH

3 MeV 5 MeV 17 MeV

2 gap Spoke 5 cell elliptical
352 MHz 704 MHz
β=0.35 β=0.47 β=0.65

100 MeV 200 MeV

600 MeV 4 mA

Beam Dump
IFMIF

International Fusion Material Irradiation Facility

- High flux source of fast neutrons
- Development of new material for fusion reactors
- Up to 100 dpa/fpy
- Liquid Li target

Reference design: Alvarez!

- Beam: 40 MeV Deuterons
- Beam current 2x125 mA
- Beam power: 10 MW
- Duty cycle 100%
- RFQ/CH combination with 175 MHz
r.t./s.c. CH-linac for IFMIF

Main advantages

Stable cw operation without thermal problems

Significant operational cost savings: 5 MW → 45 Mio kWh/a
IFMIF IAP Proposal: sc CH-Linac
## People

<table>
<thead>
<tr>
<th>Person</th>
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<tbody>
<tr>
<td>U. Ratzinger</td>
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<tr>
<td>H. Klein</td>
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<tr>
<td>H. Podlech</td>
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<tr>
<td>H. Liebermann</td>
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<tr>
<td>C. Zhang</td>
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<tr>
<td>A. Bechtold</td>
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<tr>
<td>C. Clemente</td>
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<tr>
<td>R. Tiede</td>
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<tr>
<td>M. Busch</td>
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<tr>
<td>F. Dziuba</td>
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<tr>
<td>D. Bänsch</td>
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<tr>
<td>I. Müller</td>
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</tbody>
</table>
Conclusion

• The CH-structure is a very efficient DTL-Structure
  → larger real estate gradient, smaller number of sub-systems
  → reliability, cost reduction

• Suitable for room temperature and superconducting operation

• Prototypes have been developed and tested successfully

• Projects: FAIR p-linac, EUROTRANS, IFMIF
Thank you for your attention
Effective Shunt Impedance of DTL-Cavities
r.t. CH-cavity and MEBT for EUROTRANS

Steerer diagnostic

~ 215 cm

~ 175 cm

~10 cm | ~10 cm | ~10 cm

~15 cm
Envelopes r.t. CH-cavity

![Graph showing beam envelopes and axial positions of QUADS and TUBES](image-url)
Beam Dynamics (KONUS)
Code: LORASR

KONUS (Combined Zero Degree Structure)

0-degree-sections reduce rf defocusing
→ Less focusing elements required
→ long lens free sections
→ slim drift tubes
→ high shunt impedance

→ Strong triplet-channel