Pulsed quadrupoles for novel accelerators.

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**ARES / SINBAD**

- Catch highly divergent beams from plasma accelerators & focus SC dominated bunches into plasma (avoid $\varepsilon$-growth)

**LUX**

- Current solutions:
  - Permanent magnets
    - Fixed gradients / homogeneity issues
    - Radiation-induced demagnetization
  - Plasma lenses
    - Transverse homogeneity issues
    - Limited applicability due to plasma wakefields
Pulsed quadrupoles

- Normal conducting air-core coils with \( \cos(2\theta) \)-shape (right figure)
- GSI-development for heavy ion beam final focus (75 T/m in 100 mm beamline aperture @400 kA)
- High pulsed currents (>10kA)
- Passive cooling sufficient due to short pulse durations
- High current ramp rates
- Conductors compound of litz wires for homogeneous current distribution
- Target: 200 T/m, 20 mm length (SINBAD PM quadrupole triplet consideration)
Preliminary simulations

→ First 3D model conductor dimensions:

<table>
<thead>
<tr>
<th>Inner diameter</th>
<th>16mm</th>
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<tbody>
<tr>
<td>Thickness</td>
<td>3mm</td>
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<tr>
<td>Straight section length</td>
<td>20mm</td>
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Electrical current scaling with conductor geometry:

- **Graph 1:**
  - Plot of \( I(200T/m) \) vs. \( R \) (mm)
  - @ \( d = 2.5 \text{mm} \)

- **Graph 2:**
  - Plot of \( J(200T/m) \) vs. \( d \) (mm)
  - @ \( R = 8 \text{mm} \)
At 28 kA a homogeneous gradient of $\sim 197 \frac{T}{m}$ is reached in the GFR.

Conductor aperture 16 mm in diameter - higher gradients by

- decreasing aperture
- increasing current
- adding magnetic shield (?)
3D simulation @ 28 kA

Good field region (GFR) quality requirements met within inner radius of ~4 mm (<1·10^{-2} threshold line in red)
Effective length

Calculation of the effective length of the quadrupole in z direction

\[ L_{eff} = \int \frac{G \, dz}{G_{center}} = 33.8 \text{mm} \]
Conductor heating

Heat loss in conductor:

\[ P_V = \frac{\rho}{A} \cdot l \cdot J^2 \cdot A^2 = \rho \cdot l \cdot J \cdot I \]

\rightarrow \text{trade-off between } I \text{ & } J

Heat transport in conductor:

\[ \dot{Q} = \lambda \cdot A \cdot \frac{T_{\text{hot}} - T_{\text{cold}}}{l} \]

\[ \rho \cdot l \cdot J^2 \approx \lambda \cdot \frac{T_{\text{hot}} - T_{\text{cold}}}{l} \]

\rightarrow T \text{ only depends on } J

\leftrightarrow \text{ conductor cross section}
For assumed parameters (R=8mm, d=3mm) of A=27 mm², l=0.16 m, ρ=1.7e-2 Ω mm²/m, 28 kA, 10 Hz and max. 10 W loss allows:

\[ I(t) = I_0 \cdot sin(2\pi \cdot \frac{t}{T}) \]

\[ \int_0^{\frac{T}{2}} R I^2 = R I_0^2 \cdot \frac{T}{4} \]

\[ T \approx 50 \, \mu s \rightarrow \sim 25 \, \mu s \text{ pulse length maximum} \]
Power supply circuit

- Recirculation of energy
- Bipolar capacitor
- $L_{\text{dummy}} \gg L_{\text{quadrupole}}$
  → Reduced dummy switch power
- Energy saving ~80%
Conclusion

> Proposal of **pulsed quadrupoles** for highly divergent beams into & out of plasma accelerators (e.g. SINBAD, FLASHForward, LUX)

> Simulations show **feasibility of ~200 T/m** in compact setup

> Full gradient electronics components commercially available

> **If funding & engineering manpower** is committed:
  
  - Low current **prototype (≤ 1 kA) could be built & tested at PITZ** (test electronics & beamline position available)
  
  - Learn about mechanical assembly & stability ( & e.g. noise…)
  
  - Test accuracy of simulations
  
  - Prove beam stability
Thank you for your attention!
30kA electronics

Needs for 30 kA pulses:

- ~ 5 kV
- ~ 10 µF
- Power switch

PT85QWx45
Thyristor
DYNEX (UK)
4.5 kV
~37 kA
+ Diode

TDI1-50k/16
Pseudospark switch
Pulsed Technology (RU)
25 kV
70 kA