On the Way to a Relativistic Electron Cooler

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Outline

• Status, Projects, Motivation
• Special Features
• Engineering Problems
• On the Way to 4-8 MeV Electron Cooler for HESR
Electron Cooler - Status and Projects

- **In operation state of the art**
  
  25 - 350 kV at CERN, GSI, IMP Lanzhou, FZJ ...

- **Operated** September 2005 – September 2011
  
  4.3 MV at FNAL (DC, non-magnetized)
  Longitudinal cooling time > 1h

- **Commissioned** at FZ Jülich 2013
  
  2 MV for COSY (DC, magnetized)

- **Projects**
  
  2.5 MV for NICA collider (DC, magnetized)
  4-8 MV (?) for HESR, ENC (DC, magnetized)
  (Coherent Electron Cooling – proof of principle?)

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Relativistic Electron Cooling

Proton Energy Versus Electron Energy for Cooling $v_i = v_e$

$$\langle \vec{v}_i \rangle = \beta \vec{c} = c \vec{0}_e$$

$$\beta = \frac{v}{c} = 3 = 3$$

$$T_{kin_i} = \frac{E_{0i}}{E_{0e}} \cdot T_{kin_e}$$

State of the art

100 keV e$^-$

300 keV e$^-$

COSY 180 MeV p

550 MeV p

300 keV e$^-$

180 MeV p

Proton Energy [MeV]

100 keV e$^-$

300 keV e$^-$

Electron Energy [MeV]

5000

10000

15000

20000

1

2

3

4

5

6

7

8

9

10

COSY (final energy 2.9 GeV)

3.7 GeV p

2 MeV e$^-$

FNAL 8 GeV p$^-$

4.3 MeV e$^-$

8 MeV e$^-$

HESR 15 GeV p$^-$

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The 4.3 MeV electron cooler at the RECYCLER ring (FNAL) achieves cooling time of about 1 h. Small longitudinal magnetic field in the cooling section (~100 G non-magnetized optics).

The new coolers for COSY and HESR should provide a few orders of magnitude more powerful longitudinal and transverse cooling that requires new technical solutions.

The basic idea of the COSY cooler and for the future HESR cooler is to use high magnetic field along the orbit of the electron beam from the electron gun to the electron collector.
THE 2 MEV ELECTRON COOLER HAS THE HIGHEST ENERGY OF ALL COOLERS THAT WERE MADE BASED ON THE IDEA OF MAGNETISED COOLING AND TRANSPORT OF THE ELECTRON BEAM.

- Built at BINP, joint commissioning by BINP and COSY teams at COSY in 2012-2013
- To be used at HESR (at injection energy)
2 MeV electron cooler in COSY commissioned in 2013 at Jülich
Stochastic Cooling & Electron Cooling
Energy=1660 MeV, Proton le=300 mA

From V. Kamerdzhiev

Vertical Beam Profile
Time=0 sec: Green
1080 sec: Red

Horizontal Beam Profile
Time=0 sec: Green
1080 sec: Blue

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Motivation

- Higher Luminosity at COSY with cooled beams

  Limits of the COSY stochastic cooling system
  \[ \rightarrow \text{Luminosity} \leq 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \]

  Requests for future COSY experiments
  \[ \rightarrow \text{Luminosity} \geq 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]

  Combination of electron and stochastic cooling at the same high beam energy

- FZJ IKP responsible for the High Energy Storage Ring HESR in the FAIR project

- Challenge: Development of the high energy electron cooler for HESR/FAIR (4.5 MeV - 8 MeV)
High Energy Storage Ring, HESR

- Circumference 574 m
- Momentum (energy) range 1.5 to 15 GeV/c (0.8-14.1 GeV)
- Injection of (anti-) protons at 3.8 GeV/c
- Acceleration rate 0.1 (GeV/c)/s
- Electron cooling up to 8.9 GeV/c (4.5 MeV electron cooler)
- Stochastic cooling above 3.8 GeV/c
## Modes of Operation with PANDA

<table>
<thead>
<tr>
<th>Experiment Mode</th>
<th>High Resolution Mode</th>
<th>High Luminosity Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Hydrogen Pellet target with $4 \times 10^{15}$ cm$^{-2}$</td>
<td></td>
</tr>
<tr>
<td>rms-emittance</td>
<td>1 mm mrad</td>
<td></td>
</tr>
<tr>
<td>Momentum range</td>
<td>1.5 – 8.9 GeV/c</td>
<td>1.5 – 15.0 GeV/c</td>
</tr>
<tr>
<td>Intensity</td>
<td>$1 \times 10^{10}$</td>
<td>$1 \times 10^{11}$</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$2 \times 10^{31}$ cm$^{-2}$ s$^{-1}$</td>
<td>$2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>rms-momentum resolution</td>
<td>$5 \times 10^{-5}$</td>
<td>$1 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Vision:
**Electron Nucleon Collider @ FAIR**

Add e-beam@HESR
3 GeV, 2A pol. Electron beam
15GeV, 0.4 A pol. Proton beam
$s^{1/2}=14$GeV (center of mass energy)

Ion ring and Detector funded and under construction within the FAIR complex:

**Extensions & solutions needed:**

**Protons:**
- Polarized proton source
- tune jump Quads in SIS18
- direct SIS-18/HESR beamline
- cooler solenoid+helical dipoles as SNAKE
- electron cooling at maximum energy

**Electrons:**
- polarized electron source
- full energy injector (synchrotron or pulsed linac)
- electron storage ring (in HESR tunnel?)
- spin lifetime under synchrotron radiation
- increased complexity: e+/e- beam dynamics together with spin stabilization.

**Both:**
IR + beam separation + polarization

Luminosity: $2-6 \times 10^{32}$ [cm$^{-2}$ s$^{-1}$]

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Special Features of Relativistic Electron Cooling

Technical Challenge:

**High Voltage** \((E_e > 0.5 \text{ MeV, } I_e < 3 \text{ A, confinement in a magnetic field})\)

**Magnetic field quality, straightness** in cooling section \(< 10^{-5}\)

*Decreasing of “corrugation, waviness” of force line of the magnetic field is essential for obtaining maximum of friction force*

cooling time increases with \(\propto \beta\)

**experiment ???**

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High voltage generators (> 0.5 MV)

High voltage performance

Limiting performance of accelerator tubes

Power transmission to accelerator “head”

Power transmission to magnetic coils (at accel/decel tubes)

Electron current and HV stability (1-3 A, $10^{-5}$)

Electron beam formation, transportation and recovering

Magnetic field measurement in the cooling section (straightness < $10^{-5}$)

Electron beam diagnostics
High Voltage Generators

Cockroft-Walton accelerator – up to 1 MV (practically)

˝Electron- Beam Ventil˝ (ELV, BINP Novosibirsk)-
a sophisticated version of insulating core transformer ≤ 2 MV (COSY 2MV)

Dynamitron ~ 4 MV max

Van de Graaff accelerators

Pelletron (Fermilab 4.3 MV)

˝Record holder˝ of DC accelerators: Vivitron (Univ. Louis Pasteur, Strasbourg)

→ 35 MV project, 25 MV operation
Power Transmission to Magnetic Coils (at accel/decel tubes)

Rotating shafts (Fermilab, Pelletron)

Cascade transformer (solution at 2 MeV COSY)

New:
Gas turbine (idea of BINP)

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On the Way to 4-8 MeV Electron Cooler for HESR

Gas Driven Turbine for individual power supplies of **solenoid coils** in the acceleration/ deceleration column and **high voltage** generation

High Voltage Section

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section thickness</td>
<td>4 cm</td>
</tr>
<tr>
<td>Distance between two sections</td>
<td>2 cm</td>
</tr>
<tr>
<td>Section period</td>
<td>4+2=6 cm</td>
</tr>
<tr>
<td>Electric field between two sections</td>
<td>60 kV / 2 cm = 30 kV/cm</td>
</tr>
<tr>
<td>Electric field along tube</td>
<td>60 kV / 6 cm = 10 kV/cm</td>
</tr>
</tbody>
</table>

Modular concept

BINP design

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Next Step: using more powerful turbines (reducing the number of turbines) in combination with cascade transformers (COSY type) or direct powering of the HV-solenoids with a turbo generator.
Hybrid System- Combination of Powerfull Turbines (5 kW) and Cascade Transformers
(Helmholtz Institut Mainz)

Dimension of high voltage vessel

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Powering the HV-solenoids with a Cascade Transformer

600 kV per modul, several small HV-solenoids (COSY-type)

BINP design
Direct Powering of the HV-solenoids with a Turbo Generator

HV-solenoids consist of four coils, HV generated e.g. by a Cockcroft-Walton-Generator
Industrie: Green Energy Turbine (GET)

\[ P = 5 \text{ kW} \]
\[ p_{\text{in}} = 4 \text{ bar} \]
\[ \dot{V} = 4 \frac{\text{m}^3}{\text{min}} \]
\[ m = 20 \text{ kg} \]
\[ r_{\text{max}} = 220 \text{ mm} \]
Turbine Test Bench in HIM Mainz

Compressor 40 kW

Pressure tank and turbine

5 kW turbine DEPRAG

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First Measurements with the GET Turbine

Power as function of DC current:

- Power as function of frequency:

- DC current as function of frequency:

- Power as function of input pressure:

5 kW

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Temperature Regime of the GET Turbine
(using output gas for cooling)

- Air output temperature
- Air input temperature
- Generator temperature
- Turbine temperature
- Air output temperature

Time [min]
Temperature [°C]
Next Step - one Modul for a 8 MeV Electron Cooler
(generating high voltage 600 kV, and power 2 kW for magnetic coils)

diameter 3 m

turbine
Critical point: **efficient** generation of pressurised gas (turbine input). Alternative way to a compressor could be the ORC process.

The advantage in contrast to the compressor is that residual heat of other devices can be used, which would otherwise be wasted. Hence the operational costs could be reduced significantly.
Outlook / Next Steps

• Studying turbine performance: reliability, life time at HIM Mainz

• Oil and fat free bearings - DEPRAG company

• Design and construction of a test module at BINP with DEPRAG turbine (operating with air)

• Investigation of ORC cycle based on SF$_6$ at University Bayreuth

• Preparation SF$_6$ test bench at HIM Mainz using BINP module (operating with SF$_6$)
Thank you for your attention!

Thanks to my colleagues

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