Progress of the stochastic cooling system of the Collector Ring


COOL‘13, Mürren, Switzerland
Short bunch of hot secondary beam (pbars/rare isotopes) from production target into the CR

After bunch rotation & adiabatic debunching, the $\delta p/p$ of the coasting beam is low enough for stochastic cooling of all particles

Fast 3D stochastic cooling necessary for maximum production rate of secondary beams

The CR provides the HESR (i) with pre-cooled pbars for accumulation as planned in the first FAIR phase and (ii) with (pre-cooled) stable ions/rare isotopes for in-ring experiments

<table>
<thead>
<tr>
<th></th>
<th>Antiprotons 3 GeV, $10^8$ ions</th>
<th>Rare isotopes/stable heavy ions 740 MeV/u, cooling of $10^8$ ions (max. $10^9$ ions in ring)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\delta p/p$ (rms)</td>
<td>$\delta p/p$ (rms)</td>
</tr>
<tr>
<td></td>
<td>$\varepsilon_{h,v}$ (rms) [\pi \text{ mm mrad}]</td>
<td>$\varepsilon_{h,v}$ (rms) [\pi \text{ mm mrad}]</td>
</tr>
<tr>
<td>Before/after cooling</td>
<td>0.35 % / 0.05 %</td>
<td>0.2 % / 0.025 %</td>
</tr>
<tr>
<td></td>
<td>45 / 1.25</td>
<td>45 / 0.125</td>
</tr>
<tr>
<td>Phase space reduction</td>
<td>$9 \times 10^3$</td>
<td>$1 \times 10^6$</td>
</tr>
<tr>
<td>Cooling down/cycle time</td>
<td>$\leq 9$ s / $10$ s</td>
<td>$\leq 1$ s / $1.5$ s</td>
</tr>
</tbody>
</table>
Challenges and design criteria

Main issue for antiprotons: increase ratio

\[
\frac{\text{Schottky signal } (\propto Q^2)}{\text{thermal noise}}
\]

Main issue for rare isotopes: undesired mixing (from PU to K)

- Pick-up electrodes cooled at 20-30K
- Plungeable pick-up electrodes i.e. moving closer to the beam during cooling
- Notch filter momentum cooling for noise suppression around revolution harmonics
- Pre-cooling (1st stage) with Palmer method
- Cooling (2nd stage) with the notch filter
Prototype PU tank at GSI

**Technical challenge cryoshield:**
made of oxygen-free copper, gilded galvanically to reach very low thermal emissivity (expected < 2% from measurements performed on specimens in our lab)

Preparation of mounting pieces and test-assembly of the Cu-cryoshield in the prototype pick-up tank
July 2013: gilding of the cryoshield by contractor
3D stochastic cooling of coasting secondary beams (antiprotons @ v = 0.97c, rare isotopes @ v = 0.83c).
Beam revolution frequency (period) ~ 1 MHz (1μs).

System bandwidth = 1-2 GHz

3D cooling branches and their purpose

Pick-ups HL, VL → Kickers HL, VL
notch filter longitudinal cooling method
• antiproton cooling;
• rare isotopes final-stage cooling;
• stable ions cooling.

Palmer pick-up → Kickers KHL, KVL
Palmer 3D cooling method
rare isotopes 1st-stage cooling (pre-cooling)
Slotline electrodes for PUs (HL/VL)

- UHV-compatible
- broadband within 1-2 GHz
- high coupling impedance to the beam
- mechanically robust for plunging

End 2012: first electrode ceramic plates delivered; metallisation pending

→ Poster WEPPPO20
Challenging PU vacuum tanks

Cryo-cooling reduces considerably the thermal noise originating from the pick-up structures.
Examples: CERN AC, FNAL

Plunging is a very effective way to increase the transverse sensitivity (AC, AD) and can be used together with cryo-cooling (but it's a mechanical challenge)

F. Caspers: Design Aspects for Stochastic Cooling. System Components
Hirschegg Workshop Feb 2002

Highest priority = testing the critical technical concepts

- Robust, programmable, water-cooled linear motor drive units for synchronous movement of the electrode double-modules
- Electrode modules sliding along flexible BeCu sheets cooled by cryoheads at 20-30 K
- Intermediate cryoshield at 80 K

C. Dimopoulou, TUAM1HA01, COOL13
Prototype PU tank at GSI

2 m long vacuum tank
Prototype PU tank at GSI

2 new linear motor drive units (designed & manufactured in 2012)

- Sliding cage bearing balls
- Sliding carriage
- Spring
- Light high-strength aluminium
- Guiding rod
- Linear motor
- Accelerometer
- End switches
- Dampers with longer braking distance

2013: re-assembly in the tank & synchronous tests at room temperature planned
Rare isotopes have high $Q$, hence offer strong signal.
Faltin electrodes have flat frequency response but are large and insensitive.
Faltin pick-ups are suitable for pre-cooling of RIBs.
Plunging is not necessary.

Palmer cooling signal combination for vertical and simultaneous horizontal and longitudinal cooling.
The Faltin rail is divided into cells and simulated with the HFSS code.

The structure is optimised in the band 1-2 GHz
- for maximum PU and kicker impedance
- small and flat output signal phase w.r.t. the particle pulse

- The transmission coefficient $S_{21}$ is also calculated at each frequency to ensure there are minimal reflections.

→ Poster WEPP021
2012: First layout of HF signal processing components for all cooling branches typically, small series of HF components with stringent requirements for amplitude flatness & phase linearity in the band 1-2 GHz

Ongoing refinements in interplay with lattice/building and physics requirements

Example: specification of the dynamic range for the medium power level amplifiers to cover all foreseen operation modes with beam
Example: PU tank signal processing

Beta switch: design ready, started in-house assembly of the small series

PU module controller: to be designed

Low-noise (NF ≤ 0.5 dB, $T_N \leq 35$ K) preamplifiers at room temperature (290 K): procurement in 2017
Notch filter with optical delay line

Notch filter (Thorndahl’s method): pushes particles towards the correct revolution frequency

Machine Beamtime 2012
4x10^6 Au^{79+} ions @ 400 MeV/u

in preparation: 2 improved notch filters for the CR(pbars/RIBs)

-24 dB deep notches within 1-2 GHz!

⇒ Poster WEPP019
Power amplifiers at the kickers

→ 8 kW installed microwave cw power (32 power amplifiers, 250 W each)

→ stringent requirements within tight tolerances inside the 1-2 GHz band:
  • constant gain (flat amplitude)
  • high phase linearity

→ short electrical length

Call for tender started
Large cost factor for the SC system
Simulations of cooling of antiprotons

Longitudinal cooling of $10^8$ antiprotons with notch filter in band 1 – 2 GHz

main goal: 10 s cycle time

t=0, 2.5, 5, 7.5 and 10 s

g=150 dB; t=10 s

using the CERN code cross-checked with T. Katayama/H. Stockhorst
Simulations of cooling of heavy ions

Longitudinal cooling (notch filter/TOF) of *stable* ions with the pickups HL/VL

- RIB lattice CR68: $\eta=0.176$ ; $\eta_{pk}=0.128$; $x=0.369$ (PU-K/circumference)
- response of the designed slotline electrodes; no plunging assumed.

Reference ions (coasting beam) @ 740 MeV/u: $U^{92+}$ and ion with $Q=50$

- Initial rms momentum spread $\delta p/p$:
  - within notch filter/TOF acceptance
  - small so as to avoid band overlap (not in the FP)

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>$f_0$</th>
<th>$Q_x$ ($Q_y$)</th>
<th>Overlap @ 1 GHz</th>
<th>Overlap @ 2 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.176</td>
<td>1.124 MHz</td>
<td>3.17 (3.67)</td>
<td>$\delta p/p$ (rms)$=5.4 \times 10^{-4}$</td>
<td>$\delta p/p$ (rms)$=2.7 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Longitudinal cooling of $10^8 \text{U}^{92+}$ ions with notch filter in band 1 – 2 GHz

$t=0, 0.9, 1.8, 2.6$ and $3.5 \text{ s}$

Particle noise scales with $Q^2$, thermal noise negligible

$\rightarrow$ same results for ions with $Q=50^+$ and $+6 \text{ dB}$ more gain

But, main goal: 1.5 s cycle time for hot rare isotopes
(Palmer pre-cooling followed by notch filter cooling)
Simulations of cooling of heavy ions

$10^8 \text{ } U^{92+}$ ions

$g=74 \text{ dB}$

Notch filter

$\sigma_{p/p} = 5 \rightarrow 3 \cdot 10^{-4}$

in 2.8 s

TOF

$\sigma_{p/p} = 5 \rightarrow 3 \cdot 10^{-4}$

in 7 s
TOF cooling $10^8$ U$^{92+}$ ions

$g=74$ dB

Agreement within a few %, also for notch filter cooling!

$\sigma/p$ normalised to initial value

$\sigma/p = 5 \rightarrow 3 \cdot 10^{-4}$ in 7 s

Time-domain simulation by Lars Thorndahl

frequency-domain Fokker-Planck (CERN code)
Cooling simulations in the time domain

t-domain gain $\leftrightarrow g=76\text{dB}$

$\sigma_p/p = 2 \rightarrow 1.4 \cdot 10^{-4}$ in 2 s

$g=76\text{dB}$

no incoherent effects

with incoherent effects

f-domain; with incoherent effects

notch filter cooling $10^9 \ U^{2+}$ ions
Next goals

• Procurement contract for the power amplifiers

• Prototype pick-up tank:
  - Intensive tests of the challenging mechanical concepts at room temperature
  - First cryogenic test with cryoheads, cryoshield and movable electrode dummies
  - Commissioning of the testing chamber for linear motor drive units

• Ongoing specification and in-house developments/production of the Palmer pick-up, the notch filters and other HF components

• Testing of new operation programs at the ESR stochastic cooling system

• Simulations of the system performance have to proceed at low priority and mainly with support from external experts

Thank you for your attention!