HESR Stochastic Cooling System, Design, Construction and Test Experiment at COSY

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Outline

• History of slot-ring structures
• Proof of structures at COSY and Nuclotron
• First experiments with HESR cooling tanks at COSY
• Next steps
History of slot-ring couplers

COSY SC was based on AA-design from CERN using a plunging system:

- Aperture change: 140 mm – 20 mm
- Min cycle-length: 4 sec
- Skewing and asymmetric movement possible

But the used stepper-motor driven plunging caused the most downtime of the SC

Complicate and expensive
Movable Electrode Bars for Vertical Cooling Plane
One Vertical Pickup Tank
Horizontal Pickup Tanks
Octagonal structures

Aperture of HESR much smaller (90mm) than COSY aperture (140mm)

-> looking for a structure without plunging
Slot-ring couplers

- At the same time Lars simulated slot-couplers, so why not making beam surrounding slot-couplers with octagonal arrangement of electrodes
- Besides round slot-ring we analyzed also AC-type loops, printed loops and modified CR-type structures
Slot ring couplers

- Self-supporting structure
- No plunging
- All three cooling planes with same structures
- No aperture reduction
- 8x50 Ω electrodes for broadband operation
Stochastic cooling at HESR

Each kicker of the main system can be used for horizontal, vertical or longitudinal cooling.

**Stochastic cooling with two systems**
- Main system: 2 - 4 GHz (2 PU, 3 Kicker) each tank with 64 slot ring coupler
- Additional system: 2 - 4 GHz (1 PU, 1 Kicker) with combiner-boards optimized for beta = 0.77 to cool heavy ions at lower momenta
- ToF and filter cooling
Test tank with lambda/4 printed loop structures and slot ring structures

longitudinal: red slot-coupler, blue lambda/4

vertical sidebands: red slot-coupler, blue lambda/4
Pickup tests at COSY

16 rings in test-tank cooled down to 30K:

Beta-functions at TP1: Horizontal 5.2 m
Vertical 14 m

Slot coupler: red vertical, blue horizontal

Betatron sidebands measured with the same structure (vertical tune close to 3.5 band overlap)
Structures for EDM (electric dipole moment) experiment based on slot-ring couplers

Bernd Breitkreutz developed slot-ring couplers for the EDM project (see Poster).

- $\beta = 0.46$
- Frequency range 350 – 700 MHz
Installation of one HESR PU and one HESR Kicker at COSY
BTF new system

- Large amplitude change
- Amplitude more or less zero above 3 GHz
- Large phase change around 3 GHz

Each component of whole system was measured, but no reason for strange behavior found.
But small longitudinal cooling was visible

ToF method

Beam was initial heated for a better visualization of cooling effect

Notch-filter cooling

longitudinal cooling with both methods visible, but with long cooling times. The cooling works like a system with reduced bandwidth.
Reason found in wrong orientation of kicker

- Combiner-boards distribute the signals to each ring with optimized delay
- Distribution different for PU and Kicker
- Simulations of wrong orientated combiner-boards show similar behavior
Additional measurements

The kicker was successfully rotated in the April shutdown 2017 and additional open loop measurements were done within a few hours end of May.

now the system acts as expected with very good phase response
Optical notch-filter

Advantage:
• compact design
• quasi dispersion-free
• Low rel. bandwidth

Disadvantage:
• high temperature dependence
• reduced dynamic range

Changes during last beam-time:
additional delay-lines in long path
optical amplifier in long path

• HESR:
  \( \eta \sim 0.06; \Delta p/p \sim 2 \times 10^{-5} \)
  \( \Rightarrow \Delta f/f \sim 1 \times 10^{-6} \)
  Higher slope of notches required
  Fibre: 30 ps/km/°C; \( \Delta t < 2 \) ps
  \( \Rightarrow \) Temp-control < 0.16°C or
• \( \Rightarrow \) phase control circuit with pilot signal
Fast BTF measurement to adjust system delay

- Two methods were used to obtain the system delay within a short measurement time: single widespan sweep with point on each harmonic and multiple sweeps of harmonics (talk Nikolay Shurkhno)
Cooling results

- Momentum: 2.425 GeV/c, $\eta \approx 0.07$
- Protons, particle numbers varied: 2E8 – 7E9
- Cycle-length for all results: 5 min

Second path:
Using two groups
combined with special
switchable delay lines
(vertical difference mode)

First path:
Either horizontal
or vertical (sum mode
or difference mode)
Longitudinal cooling 7E9 particles

Vertical Pickup

- Time
Longitudinal cooling 7\times 10^9 particles

Even particles shifted to lower energies during re-bunching were captured by the filter cooling

~ 2.3 min
Longitudinal cooling 2E8 particles

Slightly faster cooling and smaller equilibrium
Constant gain!
Instabilities visible, but no beam loss
ToF cooling (2E8 particles)

The 180° phase shift between ToF and filter cooling was realized by removing a delay of 150 ps instead of an additional 180° phase shifter.
First vertical cooling using the same transmission line as for longitudinal cooling

7E9 particles, system-delay and beam-position not yet optimized resulting in a small momentum shift
Vertical BTF with and without notch-filter
**Transverse (vertical) cooling 7E9 particles**

Even after beam centering, longitudinal part visible (limited isolation in hybrid), but does not influence transverse cooling.
Beam profile measurements with IPM

Cycle length: 5min

BCT: no particle loss

Horizontal cooling on

Horizontal cooling off
Beam profile measurements with IPM

Cycle length: 5min
Switched to vertical plane,
No other changes

BCT: no particle loss

vertical cooling on
vertical cooling off
Second path with hollow fiber line

After successful demonstration of vertical cooling, we installed a new transmission line using a hollow fiber line (very attractive for HESR).

High speed: ~99\%c
Attenuation: 10dB with FC/APC connectors and 50m length (fiber itself: <0.03 dB/m)
Sensitive against movements

temperature gradient?
Second path for vertical cooling

Second path: Using two groups combined with special switchable delay lines (vertical difference mode)

First path: Either horizontal or vertical (sum mode or difference mode)
Cooling with different groups

Signal-suppressions are different not only due to gain but also due to different delay.

Spectra were measured at 3 GHz within the loop, each point represents the maximum of upper sideband!
Vertical cooling with different gains

Higher gain increase initial cooling speed but equilibrium will be higher
-> gain control during cooling
2d cooling (long. + vertical) of 5E9 particles
Temperature at combiner-boards

Max. noise power (GaN amplifier in saturation): increase of temperature only 7.5°C within 40 min, but without reaching equilibrium

No significant temperature increase found during cooling experiments (three amplifier during longit. + vertical cooling temperature increase: 1-2°C)
Next steps: Notch-filter frequency control and system delay control (1)

Pilot signal added to PU signal

In
from PICKUP
combiner 2:1
pilot signal (1.7 GHz)

optical divider
modulator
laser
adjustable delay line
fixed delay line
controller
BP-filter
phase detector

180°Hybrid

Out

coupler 1
coupler 2

Good results during tests in the lab, but still not tested with beam
Next steps (2): Nikolay's new measurement setup (talk by Nikolay)

BTF during cooling: first quick measurement done already during last beam time

![Diagram of measurement setup]
summary

- Very fast setup of notch frequency and system delay with new programs
- Longitudinal filter and ToF cooling demonstrated
- First transverse cooling with slot-ring couplers in both planes
- GaN amplifiers work without problems (not switched off during acceleration)
- Cooling of combiner-boards at kicker sufficient
- First use of hollow fiber transmission line (50m)

Thank you for your attention