Journal of Physics: Conference Series

PAPER • OPEN ACCESS

# Recent results of HESR original stochastic cooling tanks at COSY

To cite this article: R Stassen *et al* 2018 *J. Phys.: Conf. Ser.* **1067** 052013

IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 052013 doi:10.1088/1742-6596/1067/5/052013

# Recent results of HESR original stochastic cooling tanks at COSY

**R Stassen[1], B Breitkreutz[1] and N Shurkhno[1]**

[1] Nuclear Physics Institute (IKP-4), Forschungszentrum Juelich, 52425 Juelich, Germany

**Abstract.** The High Energy Storage Ring (HESR) of the FAIR project at GSI Darmstadt will be very important for different scientific programs due to the modularized start version of FAIR. Stochastic cooling together with barrier bucket operation will be the key component to fulfil the requirements of the different experiments. First pickup and first kicker of the HESR stochastic cooling system have been installed into the COSY accelerator at FZ Juelich. COSY is well suited to test the performance of the HESR stochastic cooling hardware at different energies and variable particle numbers. The novel dedicated HESR-structures were already success-fully tested at the Nuclotron in Dubna for longitudinal cooling and during a beam test in 2017 for transverse cooling at COSY. The results of the last stochastic cooling beam time will be presented as well as the first use of GaN based amplifiers in a stochastic cooling system. The HESR needs fast transmission-lines between PU and KI. Beside air-filled coax-lines, optical hollow fibre-lines are very attractive. First results with such a hollow fibre used for the transverse signal path will be presented.

## 1. HESR stochastic cooling

Stochastic cooling is a well-established technique at many facilities worldwide using different structures and frequencies [1]. Dedicated structures were designed for the HESR stochastic cooling system, which is - together with moving barrier buckets - a key component for a successful operation of the HESR in the FAIR modularized start version. Due to the postponed accumulation ring RESR (Recycled Experimental Storage Ring) the anti-proton beam has to be accumulated in the HESR [2]. Meanwhile one pickup (PU) and one kicker (KI) of the HESR stochastic cooling system have been built and installed into the COSY ring at FZ Juelich for testing the cooling performance and verifying the simulation results [3].

### *1.1. System setup during beam-time in August 2017*

COSY was operated with protons at a momentum of 2.425 GeV/c with a measured slip factor of $\eta$ = -0.07. This corresponds to the favourite working point of HESR considering the lower revolution frequency at HESR. The stochastic cooling installation includes original HESR components like programmable delay lines to adjust the system for different energies, low noise amplifiers, high power amplifiers and an optical notch-filter. All open-loop and cooling measurements were done with a cycle time of 5 minutes. The following kicker setup was used due to the limited number of available GaN amplifiers.

Two different signal paths were used. Group B with one high power amplifier was used for longitudinal cooling, while group D and C (each with one amplifier) combined with adjustable delay-lines were used to cool the beam in one transverse direction (Figure 1).

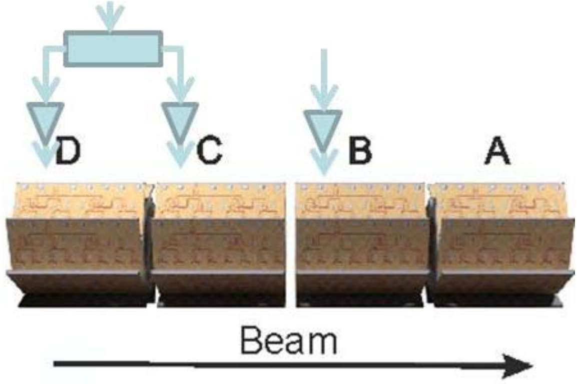


**Figure 1.** Kicker setup for longitudinal cooling (group B) and transverse cooling in one plane (group D and C).

### *1.2. Longitudinal cooling*

Notch-filter and system delay were set within a few hours with the help of an automated measurement system. Open loop measurements were carried out to adjust the system delay between PU and KI. Figure 2 shows the open-loop measurements of group D in longitudinal mode for the horizontal and the vertical plane.

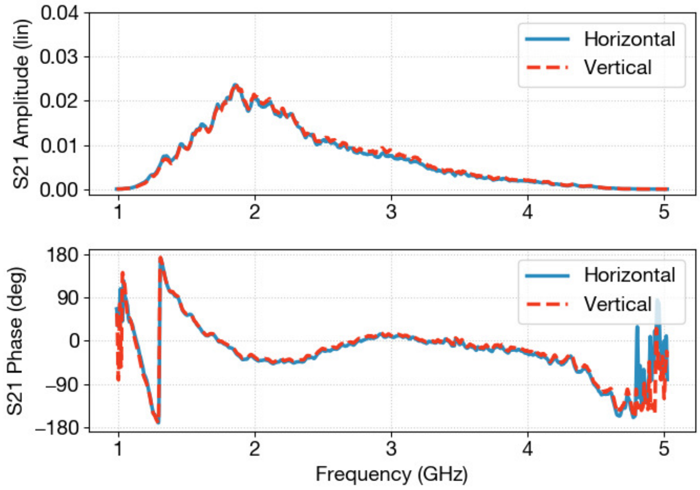


**Figure 2.** Open-loop measurements.

The frequency response is comparable to the CST simulation results of the structures [4]. The sensitivity of the structure is high enough although the maximum is not at 3 GHz as simulated with HFSS [5]. The phase change over the frequency is within +/- 25° slightly higher than the phase change of the old stochastic cooling system, but still tolerable.

Even without phase-shifter to adjust the optimum phase, cooling was immediately visible after closing the loop. The momentum spread was reduced by a factor of three within about 2.3 minutes and $7{\times}10^9$ particles (Figure 3) even without optimizing the system gain.

IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 052013 doi:10.1088/1742-6596/1067/5/052013

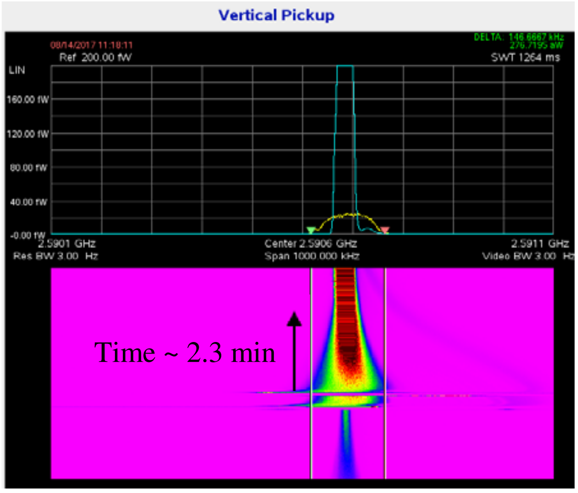


**Figure 3.** Longitudinal cooling of $7\times10^9$ particles shown at the $1700^{th}$ harmonics (reduction of frequency distribution).

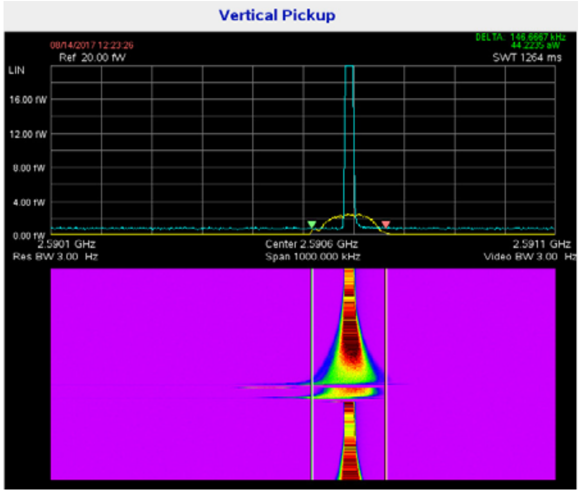


**Figure 4.** Longitudinal cooling of $2\times10^8$ particles.

Figure 4 shows the longitudinal cooling of $2\times10^8$ particles with the same setting of delay and gain. The cooling is only slightly faster than with $7\times10^9$ particles, but the equilibrium is significantly smaller. Even 'Time of Flight' (ToF) [6] cooling was demonstrated after switching off the notch-filter and removing 150 ps delay to substitute the missing 180° phase shift. Although the frequency spread is already small due to the small η value, ToF cooling was visible even without initial heating of the beam.

*1.3. Transverse cooling*

Longitudinal cooling with this structure was already demonstrated in 2013 at the Nuclotron in Dubna [7], but so far no transverse cooling. After achieving a good setup for longitudinal cooling the system was switched to the horizontal transverse plane using the same transmission line between PU and KI. Only small corrections of the system-delay were necessary to achieve the first transverse cooling with the slot-ring couplers.

Profile measurements with the ion profile monitor (IPM [8]) verified the horizontal cooling during the 5 minutes cycles (Figure 5). No influence on the vertical plane is observed indicating that no transverse coupling exists in the machine and in the cooling structures. Without horizontal cooling the beam is slightly heated by rest-gas scattering which is similarly visible in the vertical plane.

Vertical cooling was visible just by switching from the horizontal to the vertical plane without any further changes (Figure 6).

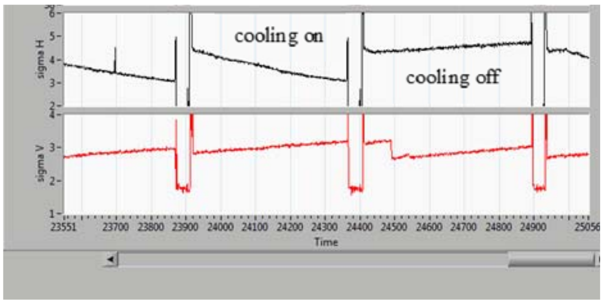


**Figure 5.** Beam profile measurements of horizontally cooled beam (horizontal: black, vertical: red).

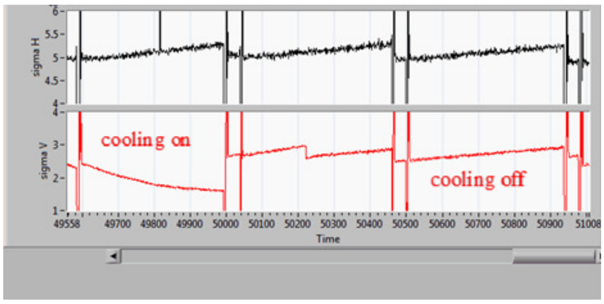


**Figure 6.** Beam profile measurements of vertically cooled beam.

IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 052013 doi:10.1088/1742-6596/1067/5/052013

A second signal path between PU and KI was installed using a hollow fibre line. Optical fibre lines are very attractive to transmit broadband RF-signals over a wide distance. They are easy to install, have low attenuation and zero dispersion. But standard fibres have some dis-advantages: The signal speed is only about 60% of speed of light in vacuum and these lines have a high temperature-gradient. An alternative are hollow fibre lines, where the light is guided in a hollow core which is sur-rounded by a micro-structured cladding [9]. 50m of such a line was installed as transmission-line between pickup and kicker. The line was very sensitive against movements, but once installed a stable operation was possible. Periodical changes in gain and phase - as measured in the laboratory - were not found during cooling. The hollow fibre line is used for transverse cooling of the vertical plane. Two additional lines will be installed to obtain a 3-D stochastic cooling and to verify the better temperature behaviour.
With the second path it was possible to cool the beam in the longitudinal and vertical plane simultaneously. Figure 7 represents the difference signal of the vertical plane during cooling (blue curve: before cooling, yellow curve: after 5 min of cooling). Longitudinal parts in the transverse signal will be always visible due to the high sensitivity of the structure and limited isolation in the hybrids. These longitudinal parts demonstrate the longitudinal cooling with system one. Without transverse cooling the betatron sidebands would increase as well as the longitudinal parts by longitudinal cooling, but due to the vertical cooling with the second system the amplitudes decreased. Thus, first 2-D cooling (longitudinal and vertical) was achieved although not all groups of the kicker were used.

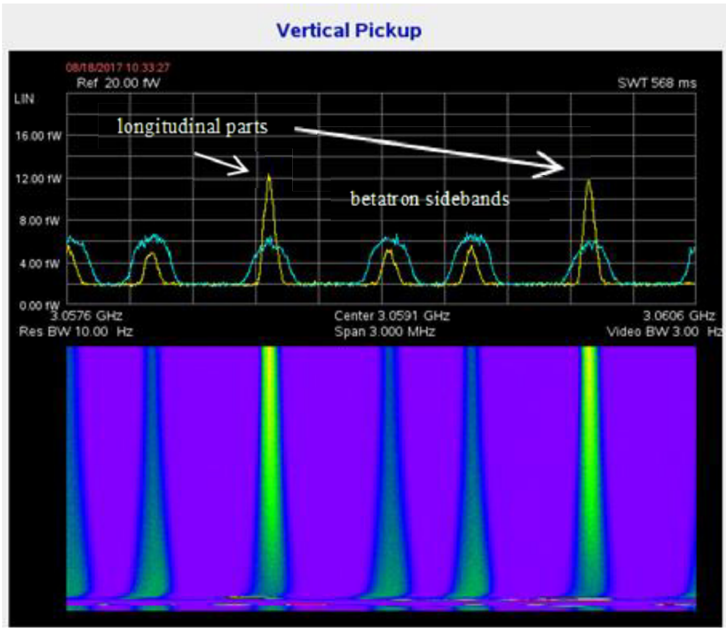


**Figure 7.** Difference signal of vertical plane.

## 2. High power GaN amplifier

One of the most critical parts in the active chains of a stochastic cooling system are the high power amplifiers. Several decades ago GaAs (gallium-arsenide) was the first choice to build linear high power solid-state amplifiers in the GHz-range. Some years ago GaN (gallium-nitride) technology became very attractive. Higher voltages and higher heat-densities allow much higher power with better efficiencies.

Stochastic cooling is mostly dominated by highly amplified noise. Noise-peaks can easily drive amplifiers into saturation. Due to nonlinearities intermodulation products (IMD) occur even far below the 1 dB compression point (P1dB). Normally, these IMD products are not visible, but with a notch-filter (comb-filter) where the noise is significantly reduced at the notches the IMDs lead to a filling up of the notch-depths. Such notch-filters are in use for longitudinal stochastic cooling, where the signals from the particles with right momentum will be suppressed at each harmonic. High notch-depths are essential for a good stochastic filter cooling. The notch-filters used at COSY have normally an average notch-depth of about 35 dB. When the average notch-depth was decreased to about 20 dB the final equilibrium of the longitudinal cooling started to increase. IMD products create additional noise which acts as an additional heating term to the beam particles. Thus cooling time and particularly the equilibrium momentum spread are increased.
Broadband high power amplifiers are commercially available, but these amplifiers do not fulfil the requirements of stochastic cooling concerning phase and group-delay behaviour. The high power amplifiers for the HESR stochastic cooling system were especially designed considering the nonlinearities of GaN-devices [10]. The main parameters are summarized in table 1. First series amplifiers were successfully operated at COSY and transverse and longitudinal cooling was demonstrated. Although the amplifiers are mounted very close to the kicker no radiation problem has appeared so far.

Table 1: Basic parameters of the GaN amplifiers.

| | | |
|---|---|---|
| Frequency | 2 – 4 | GHz |
| Gain flatness | +/- 1 | dB |
| Phase | +/- 10 | deg |
| Group-delay | +/- 100 | ps |
| P1db | 80 | W |

Most of the power from the GaN amplifiers is dissipated in the Wilkinson resistors of the combiner-boards located inside the vacuum tank. Each combiner-board is connected to a fixed water-cooled pipe by thick copper ribbons. During the 2-D cooling experiment with three amplifiers the temperature at the combiner-boards rises only about 1-2°C. Thus the passive thermal cooling of the combiner-boards is sufficient.

## 3. OUTLOOK

The first evidence of transverse cooling is an important step in the review of the HESR stochastic cooling system. The system is now prepared for quantitative measurements which can be used for systematic studies to proof the simulation codes.

## 4. REFERENCES

[1] Caspers F and Möhl D, 2012, *European Physical Journal* H 36, p 601-32.
[2] Katayama T *et al.*, May 2010, Proc. of *IPAC'10*, Kyoto, Japan, p 837-39.
[3] Stassen R *et al.*, 2009, Proc. of *PAC'09*, Vancouver, Canada, p 861-63.
[4] CST Microwave Studio, 3D Electromagnetic Simulation Software, https://www.cst.com/products/cstmws
[5] HFSS, High Frequency Structure Simulator, http://www.ansys.com/products/electronics/ansys-hfss
[6] Kells W, 1980, Proc. of the 11th Int. Conf. on High-Energy Accelerators, Geneva, Switzerland, p. 777.
[7] Shurkhno N *et al.*, 2013, Proc. of *COOL'13*, Murren, Switzerland, p 73-75.
[8] Kamerdzhiev V *et al.*, 2009, Proc. of *DIPAC'09*, Basel, Switzerland, p 191-93.
[9] Hollow fiber lines, http://www.nktphotonics.com/lasers-fibers/en/product/hollow-core-photonic-crystal-fibers/

IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 052013 doi:10.1088/1742-6596/1067/5/052013

[10] Nanowave Technologies Inc., http://www.nanowavetech.com/