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KICKER FOR THE CR STOCHASTIC COOLING SYSTEM BASED ON HESR SLOT-RING COUPLERS

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Abstract

A 'light' version of the HESR stochastic cooling system was already successfully tested in the Cooler Synchrotron COSY. There the stochastic cooling system was operated together with the original PANDA cluster jet target from University Münster. The system layout includes all components as planned for the HESR like low noise amplifier, switchable delay-lines and optical notch-filter. The robust slot-ring design has been proven. Hence it was decided to use this concept for the CR kicker as well. Therefore, the parameters need to be adapted for the CR cooling system. However, the significantly higher RF power requires a new water cooling concept. First simulations and measurements show that using heat pipes could be a possible solution. At COOL'23 main parameter as well as the promising results achieved at COSY will be presented.

STOCHASTIC COOLING SYSTEM OF HESR

The HESR is the planned High Energy Storage Ring (1.5 - 15 GeV/c) for antiprotons at the FAIR facility (Facility for Antiprotons and Ion Research) in Darmstadt (GSI) [1]. One of the key systems at the HESR will be the stochastic cooling. It is not only essential to enhance the beam quality for the experiments but is also indispensable for the accumulation of antiprotons in HESR [2]. The system is based on dedicated structures. Each beam-surrounding slot of these so-called slot-ring couplers covers the whole image current without a reduction of the HESR aperture [3, 4].

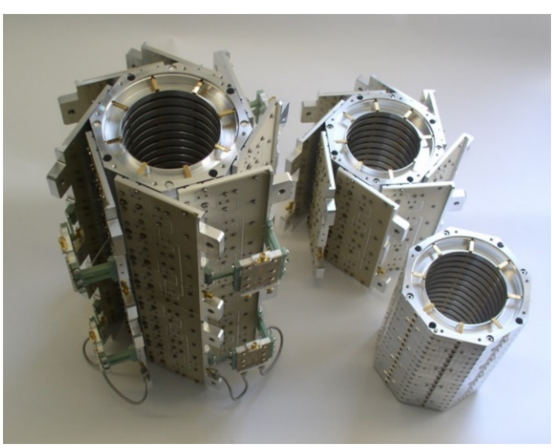

Figure 1: Stacks of slot ring couplers with and without 16:1 combiner-boards and two stacks mounted together including 2:1 combiner with heat-trap.

Each resonant ring structure is heavily loaded with eight 50 Ω electrodes for a broad-band operation. The rings are screwed together to a self-supporting structure in stacks of 16 rings. Four of these stacks will build the spindle for one tank. Figure 1 shows these stacks; one without combiner, one with combiner board and a combination of two stacks including additional 2:1 combiner especially designed to minimize the heat flow to the 16:1 combiners. The structures can be used for all cooling directions simultaneously. No complicate plunging system is needed.

A 'light' cooling version with one original pickup (PU) and kicker (KI) tank of the HESR was installed in COSY. The system layout includes all components as planned for the HESR like low noise amplifiers, switchable delay-lines, optical notch-filter and - of course - the high power amplifier. The inner structure of the pickup was cooled down to less than 20 K within 10 h. Although the tank is not bakeable, the vacuum reached already $1 \cdot 10^{-10}$ mbar. The HESR needs fast transmission-lines between PU and KI. Beside air-filled coax-lines, optical hollow fibre-lines are very attractive [5]. Three of such 50 m long fibres were installed in COSY and used during the cooling experiments. See Fig. 2 below.

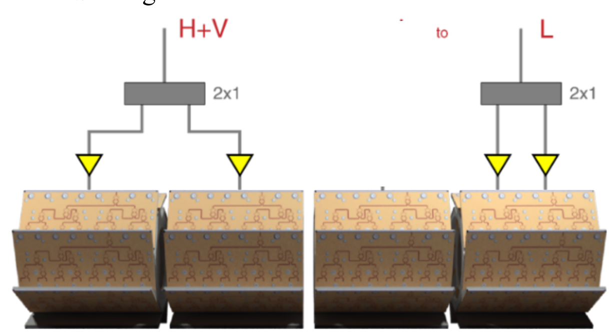

Figure 2: HESR Kicker arrangement at COSY.

The kicker tank was equipped with six custom-made HESR 100 W power amplifier based on gallium nitride (GaN) transistors. Although GaN is not as linear as Gallium Arsenide (GaAs), it is meanwhile the first choice of broadband power amplifier in the GHz region. The kicker is used for all three cooling planes. Two groups of the HESR kicker are for both transverse planes and one group with two amplifiers for longitudinal cooling.

PANDA TARGET MEETS HESR STOCHASTIC COOLING SYSTEM IN COSY

The HESR originally has been optimized for the PANDA experiment (antiProton ANihilation at DArmstadt). The PANDA collaboration comprises more than 500 scientists coming from 20 countries. Their research is dedicated to fundamental physics research covering topics such as

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strong and weak interaction, exotic states of matter, and the structure of hadrons. One big contributor is IKP-1 of FZJ. In order to record as much information as possible from the antiproton - proton collisions a versatile detector is being built that allows precise track reconstruction, energy and momentum measurements, and efficient identification of charged particles. One of the required targets is being built by scientists at the Münster University [6]. This cluster target has been installed and successfully commissioned in COSY during summer 2018. The PANDA cluster target reached densities in the order of 1E15 atoms/cm². Such high target densities leads to fast energy loss and emittance growth of the beam. Almost all particles were lost during the 5-minute cycle.

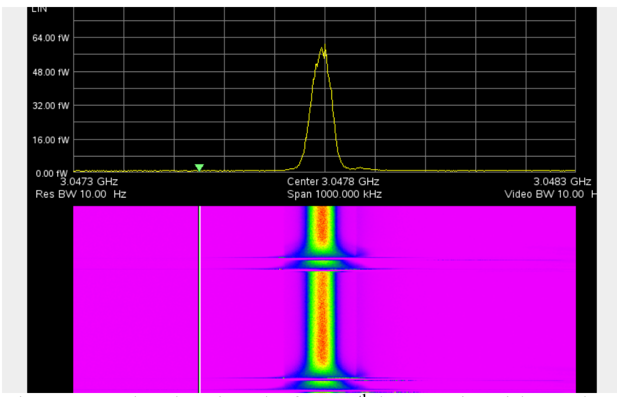

Figure 3: Schottky signal of 1500th harmonic with stochastic cooling, barrier bucket and target.

Even with the 'light' version of the HESR cooling system, cooling was demonstrated in all three directions. Each direction could be cooled by a factor of 3 to 4 without target.

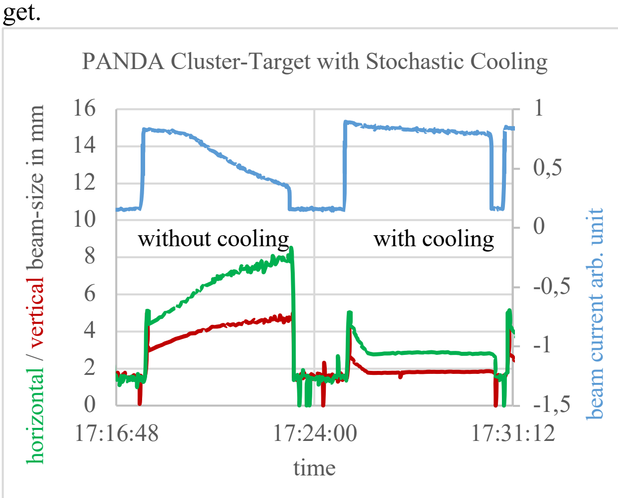

Figure 4: Beam current and beam size with (right) and without stochastic cooling (left).

With longitudinal cooling and target, a fast cooling was observed at the beginning of the cycle. The momentum spread was decreased by a factor of 2 and a very stable equilibrium was observed for the rest of the 5-minute cycle (Fig. 3).

Energy loss and beam broadening in the cluster target could be compensated efficiently. In Fig. 4 the beam current (=intensity), and the horizontal together with the vertical beam size are displayed evolving in time. The first cycle is without cooling, the second one with stochastic cooling on. The cycle time was 5 minutes.

Beam losses were significantly reduced. Transverse cooling not only compensates for beam size growth by the target, it was able to reduce the equilibrium emittance even by factor 2 in both planes.

CR KICKER DESIGN

The stochastic cooling system of Collector Ring (CR) is used to fast reduce the phase space of hot rare isotope beams (RIBs) and antiproton beams [7]. Both operation modes are designed for fixed particle velocities, i.e. 0.83 times the speed of light for RIBs (corresponds to a kinetic energy of 740 MeV/u) and 0.97 times for antiprotons (3 GeV/c). Since stochastic cooling is more sensitive to heavy particles, the kicker is optimized for the latter. The robust slot-ring design of the HESR has been proven. Hence it was decided to use this concept for the CR kicker as well. Therefore, the parameters need to be adapted for the CR cooling system. The aperture was increased to 140 mm while the operating frequency was changed to 1 - 2 GHz.

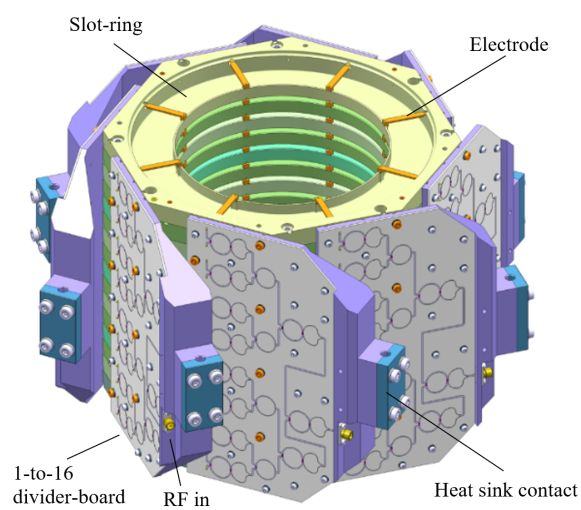

Figure 5: One stack of new CR kicker structure including divider-boards.

The slot-ring structures were optimized with CST Studio Suite for a high shunt impedance of antiprotons at a velocity of β = 0.97. The impedances are defined according to [8]. The electric fields were simulated for a cell at the centre of a long structure, and the resulting impedances were multiplied by the number of cells to obtain the total impedances shown in Table 1.

Compare to the slotline PUs from GSI, the cooling for both transverse planes can be operated at the same beam position due to the static aperture. Thus, one KI will be used for transvers cooling in both directions and one KI for longitudinal cooling. Each kicker tank contains 128 slot-

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rings. Every 16 rings are hard-wired with ceramic divider-boards as a stack (see Fig. 5). The main parameters of the new structures are summarized in Table 1.

Table 1: CR Kicker Parameters

Main parameters	Value	Unit
RF frequency range	1 - 2	GHz
Particle velocity		
Rare isotope	0.83	c_0
Anti-proton	0.97	c_0
aperture	140	mm
No. of Slot-rings per tank	128	
Total longitudinal shunt impedance for anti-protons	2816	Ω
Total transverse shunt impedance for anti-protons	896	Ω
Total longitudinal shunt impedance for rare isotopes	1280	Ω
Total transverse shunt impedance for rare isotopes	448	Ω
Nominal power loss per divider board	15 (max. 95)	W
Nominal total power loss per tank	960	W

The Wilkinson dividers at the divider-boards use SMD resistors to dissipate the odd-mode signals coming in from the electrode side. Since the electrodes are mostly a pure inductive load, all power applied by the power amplifiers is reflected and must be dissipated in these resistors. Therefore, diamond-based resistors are used. To increase the bandwidth, mostly two-staged Wilkinson dividers are used when possible. Only the third of the four divider levels is one-staged due to space limitations. The much higher power losses at the CR divider-boards compared to the HESR requires a new cooling concept. The copper bands between the divider boards and the water cooling block have been replaced by heat pipes or heat straps respectively and extensive simulations were carried out.

The used simulation model calculates the heat flow from the resistors to the water cooling considering the detailed structure of the boards, including the strip lines and thin layers of Ag past and glue. For a constant resistor power of 15 W the maximum resistor temperature will stay below 60 °C. If the power in the resistors of a circuit board is increased to 95 W for 5 minutes, the temperature in the resistors rises to ~110 °C within 0.1 s (Fig. 6). The subsequent moderate increase, which is determined by the heating of the entire board, goes up to a maximum temperature of almost 174 °C. This is already at a critical limit. Moderate temperature increase can be handled by a temperature-measurement interlock system, but the fast increase at the beginning not.

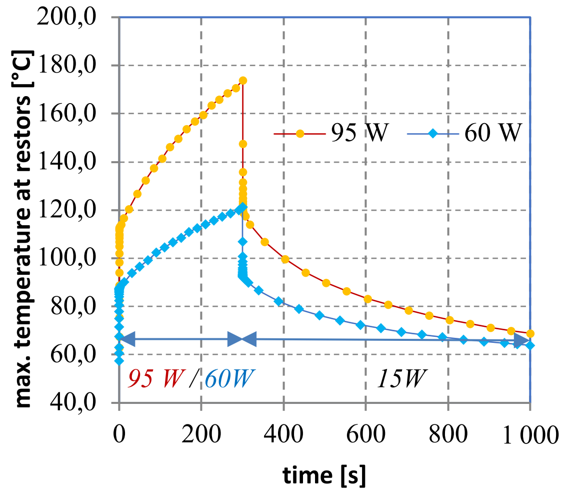

Figure 6: Simulated temperatures at resistors of the divider-boards.

The heat pipes are modelled by simplified solid bodies with high thermal conductivity, which corresponds to the heat removal capability according to the data sheet. This simplification cannot correctly describe the complex non-linear processes in the heat pipes and resulting limitations of the cooling system. This uncertainty in the parameters of the simulations require additional consideration through prototypes.

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