STOCHASTIC COOLING DEVELOPMENTS FOR THE COLLECTOR RING AT FAIR

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Abstract

A Status report on the ongoing developments for the demanding stochastic cooling system of the Collector Ring is given. The system operates in the frequency band 1-2 GHz, it has to provide fast 3D cooling of antiproton, rare isotope (RIBs) and stable heavy ion beams. The main challenges are (i) the cooling of antiprotons by means of cryogenic movable pick-up electrodes and (ii) the fast two-stage cooling (pre-cooling by the Palmer method, followed by the notch filter method) of the hot rare isotope beams. Progress in designing, testing and integrating the hardware is discussed.

INTRODUCTION

The CR stochastic cooling system is described in [1, 2]. In summary: Antiproton cooling is limited by the poor ratio Schottky signal/thermal noise, that is why it is foreseen: (i) to keep the slotline pickup electrodes at cryogenic temperatures (20-30 K), (ii) to strive for large sensitivity by moving (plunging) the pickup electrodes as the beam shrinks, (iii) for longitudinal cooling, to implement the notch filter technique, which is the best choice since it advantageously filters out the thermal noise. The chosen ring slip factor $|\eta|$=0.011 guarantees optimum momentum acceptance for the notch filter cooling, but slows down the simultaneous transverse cooling due to the high mixing M between kicker and pickup. A remedy comes from the flexibility of the CR lattice in setting different γ_{tr} values. As $\delta p/p$ shrinks during the 10 s of cooling, $|\eta|$ can be slightly increased by a factor 2-3 (decrease γ_{tr}), by small tuning of the quadrupole strength, so as to control $M(t) \sim (|\eta(t)|\delta p(t)/p)^{-1}$. At the end of cooling the beam is rebunched and extracted, then the quadrupoles must ramp fast back to their initial value ($|\eta|$=0.011) before new beam is injected. The lattice, the quadrupoles and their power supplies must be specified from the beginning for ramping in the range $|\eta| \approx 1-3\%$ within shortest time with respect to the cooling/cycle time. This $|\eta|$-ramping procedure will be optimized during commissioning with beam, at present it may be studied with cooling simulations in all 3 planes.

Heavy ion cooling is limited by the undesired mixing. In the beginning, for the hot RIBs, only the Palmer method can be applied with a dedicated pickup (pre-cooling stage). Recently, the option of time of flight (TOF) longitudinal cooling using the Palmer pickup in sum mode has been included. The TOF option can be useful for precooling the tails of hot RIB beams since it suffers less from the interplay with the horizontal betatron motion than the Palmer method. In a second stage, after δp/p has decreased, it is planned to switch to cooling with the slotline pickups and the notch filter until the final beam quality is reached.

The option of TOF longitudinal cooling for antiprotons or RIBs is useful for moderate requirements on the final $\delta p/p$ or on the cooling time (e.g. lower particle number, longer cycles) or, due to its larger momentum acceptance, as pre-cooling before the notch filter takes over.

For primary beams of stable ions coming with better quality after acceleration in the synchrotrons, one-stage cooling by the TOF or notch filter method with the slotline pickups should be sufficient.

Table 1: Required Cooling Performance in the CR. For parameters in red there is no safety margin, for those in blue larger values can be accepted with the HESR downstream.

3 GeV, 10^8 antiprotons, coasting beam

	δp/p (rms)	$\epsilon_{h,v}$ (rms) π mm mrad
Before cooling	0.35 %	40
After cooling	0.05 %	1.25
Cooling down time	≤9 s	
Cycle time	10 s	

740 MeV/u, 10^8 RIBs, coasting beam

	δp/p (rms)	$\epsilon_{h,v}$ (rms) π mm mrad
Before cooling	0.2 %	35
After cooling	0.025 %	0.125
Cooling down time	≤1 s	
Cycle time	≤1.5 s	

Table 1 shows the updated cooling requirements for 10^8 antiprotons and RIBs in the CR. In the present FAIR scenario the CR delivers to the HESR [3] pre-cooled antiprotons and stable ions/RIBs for accumulation and in-ring experiments. Taking into account the rebunching of the antiprotons/ions for transfer to the HESR as well as the small momentum acceptance of the HESR and its stochastic cooling systems, up to 30% lower final δp/p would be needed after cooling in the CR. On the other hand, higher emittances can be accepted in the HESR. For the most demanding case of 10^8 antiprotons in a 10 s cycle, the momentum spread budget should be within reach by optimizing the interplay among the longitudinal and transverse cooling in the CR, the rebunching/debunching procedures in the transfer as well as the longitudinal cooling in the HESR. The stable ions are less critical since they are initially not so hot as the RIBs.

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What is more, stable ions/RIBs can be pre-cooled longer in the CR (e.g. 2-5 s) if high beam quality is needed for precision experiments in the HESR.

PICKUP DEVELOPMENTS

Prototype Cryogenic Pickup Tank with Plunging Slotline Electrodes

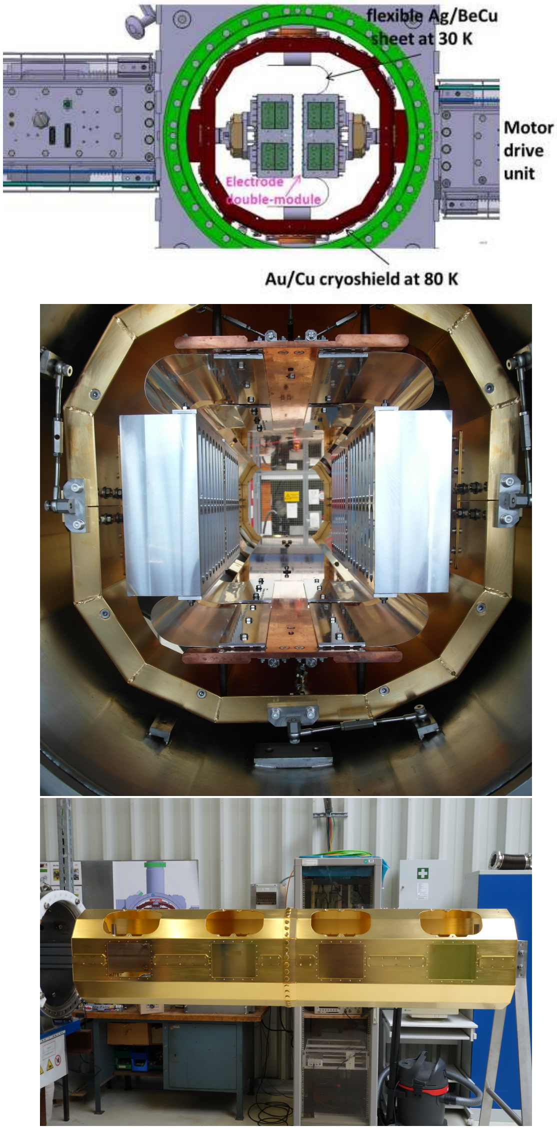

Figure 1: Section of the prototype pickup tank (2 m long, DN500COF flange), where the mechanical and thermal concepts are being tested. Top: The cryoshield, the Ag/BeCu sheets and the motor drive units driving synchronously the slotline electrode modules are shown. Middle: Final assembly in the tank before pumping down and performing the cryogenic test. Bottom: Gold-plated copper cryoshield before mounting in the tank.

Figure 1-top shows the concept in the prototype pickup tank. The movable slotline electrode modules are thermally coupled to flexible silver-plated copper beryllium sheets. These sheets are fixed on Cu bars along the tank (Fig. 1-top, middle) which are cooled by the 2nd stage of cryoheads to about 20-30 K. The intermediate cryoshield inside the pickup tank will be held at 80 K by the 1st stage of the cryoheads. It consists of 4 half-shells, each 1 m long, and bears holes for the motor drives and for assembling, it is made of oxygen-free copper, galvanically gold-plated so as to reach very low thermal emissivity (Fig. 1-bottom). The water-cooled linear motor drive units, tested synchronously in the prototype pickup tank (Fig. 1-top) at room temperature, fulfill the specifications: (i) their max. range of plunging is 70 mm following the shrinking beam size during stochastic cooling and (ii) at the end of the cycle, they move back out to their max. aperture within 200 ms, before a new beam is injected. The motor drive units are fully controlled, statically and dynamically, by real-time software.

The assembly inside the tank (Fig. 1-middle) comprising 2 motor drive units (instead of 8 in the full version) bearing dummy modules (i.e. without slotline electrodes), the flexible Ag/BeCu sheets mounted on the long Cu bars, the cryoshield and the two cryoheads (up, down on the tank) has been completed and first UHV and cryogenic tests have been performed.

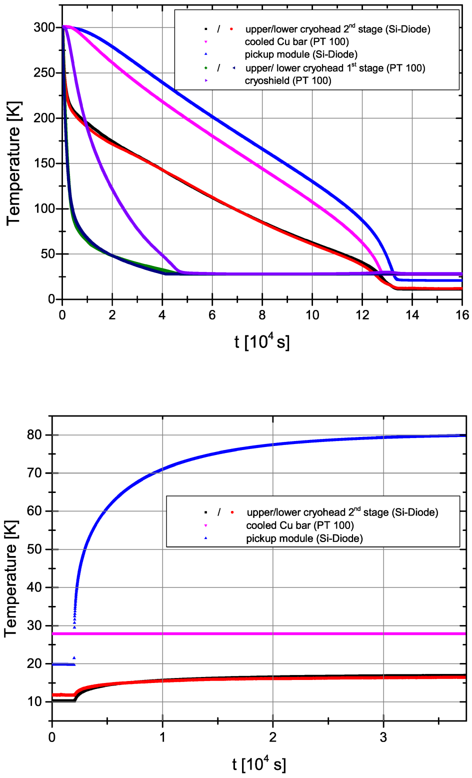

Figure 2: Temperatures of components in the prototype pickup tank versus time. The PT100 temperature sensor does not measure below 28 K, the Si-diode covers the full range. Top: Cooling down. The vacuum pressure dropped from $3 \cdot 10^{-6}$ down to $1 \cdot 10^{-9}$ mbar within $5 \cdot 10^{4}$ s. Bottom: Heating up the module simulating the heat load of 8 modules.

As shown in Fig. 2-top the 2nd stage of the cryoheads and the module reached 10-12 K and 20 K, respectively, the Cu bar temperature lied in between (i.e. in the worst case 10 K above the cryoheads 2nd stage). After cooling down, by means of resistive heating elements the module was heated up so as to simulate the expected heat load of 8 modules–in total 18 W–(Fig. 2-bottom). The 2nd stage of the cryoheads increased to 17 K, the Cu bar stayed below 28 K. These first results confirmed that the thermal concept with the 2 cryoheads and the cryoshield is appropriate (i.e. not underspecified) for the full version. Further systematic measurements and quantitative analysis are underway.

A special chamber for testing motor drive units under pre-vacuum conditions, at room temperature, was engineered, built and commissioned. It permits long-term tests in horizontal or vertical orientation in view of improvements for the final pickup tanks. It consists of 1/8 of pickup tank with Cu-cryoshield dummy and an observation window (Fig. 3). One motor drive unit with electrode module can be mounted so as to slide along the Ag/BeCu sheets. In the tests, the Ag/BeCu sheets (the ones shown in Fig. 1-middle) were found unreliable because they break after typically 10^5 cycles (aim is 10 million cycles). An improved concept for these sheets (geometry, manufacturing process) is in preparation. Systematic RF tests of a (moving) slotline electrode module can be carried out in the chamber, too.

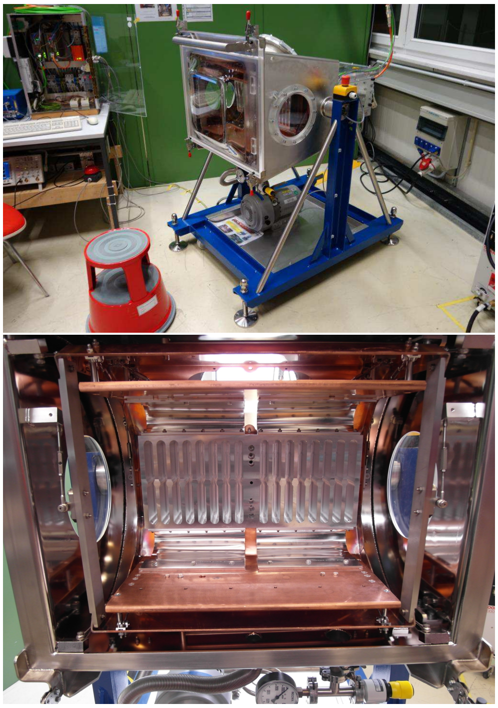

Figure 3: The chamber for lifetime tests of motor drive units and all moving components.

Palmer Pickup with Faltin Electrodes

Plunging of the pickup electrodes is not needed for pre-cooling of RIBs. A pickup with very large horizontal (± 200 mm) and vertical (± 66 mm) apertures with respect to the beam axis is specified, so as not to intercept the injected beams (before the bunch rotation). The former implies that many unwanted rf modes lie inside the cooling band 1–2 GHz, these must be damped by filling the structure with ferrite. The latter limits the sensitivity of the pickup, so that a long structure (1.7 m, 2 m pickup installation length) is needed to reach sufficient impedance, but implies high phase non-linearity in the output signal with respect to the particle pulse. After dedicated electromagnetic simulations with the HFSS code and measurements on prototypes the geometry and rf properties of the proposed Faltin structures including ferrite have been optimized in the band 1–2 GHz [4]. The solution is the best compromise for (i) maximum pickup impedance coupled to the beam, (ii) linear output signal phase with respect to the particle pulse (iii) flat frequency response $S_{21}(f)$, avoiding resonances, (iv) suppression of unwanted rf modes. Thus, the engineering of the electrodes and the pickup tank can start soon.

RF SIGNAL PROCESSING

The RF block diagram of the complete stochastic cooling system [5] and its integration into the building is being refined so as to save electrical length, since the flight time of the quasi-relativistic particles from pickup to kicker is very short. The time delay budgets from pickup to kicker have been checked including realistic electrical lengths of the designed slotline/Faltin electrodes as well as conservative assumptions for the electrical length of the kicker electrodes and all intermediate signal processing components and cables. For the power amplifiers at the kickers the specified max. electrical length of 16 ns for each unit was assumed. There is almost no margin, especially for the Palmer cooling branch of RIBs.

The signal processing chain from the Palmer pickup (at high dispersion) to the kickers (at zero dispersion) uses the 4 Faltin electrodes in difference mode for i) the vertical cooling branch and ii) the combined horizontal and longitudinal cooling branch with the Palmer method. In addition, the option of TOF longitudinal cooling by taking the 4 Faltin electrodes in sum mode is foreseen (Fig. 4). The signal processing chain from the slotline pickups to the kickers includes the transverse (horizontal, vertical) cooling branches as well as the longitudinal cooling using the notch filter or the TOF method (Fig. 4).

Recent activities on the demanding RF components in the band 1–2 GHz are reported in detail in [6]. In short: The complex pickup module controller is currently under development. The beta switch combiners and the variable attenuators have been designed, some updating and final consolidation is needed before ordering the small series. The design of the phase shifters is in good progress. A functioning prototype of the embedded powermeter is now available, after refinement the series can be ordered. In-house development of an optical notch filter and its successful implementation with beam in the ESR have been reported before [7].

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Recently, 2 optical notch filters with thermally stabilized delay lines were built and are ready for the CR (one for antiprotons at v=0.97 c, one for RIBs at v=0.83 c). Their measured RF properties fulfill the specification i.e. notch depth below −30 dB within 1–2 GHz. The water cooled 1–2 GHz power amplifiers at the kickers (250 W units) have been ordered, the preseries device is under development.

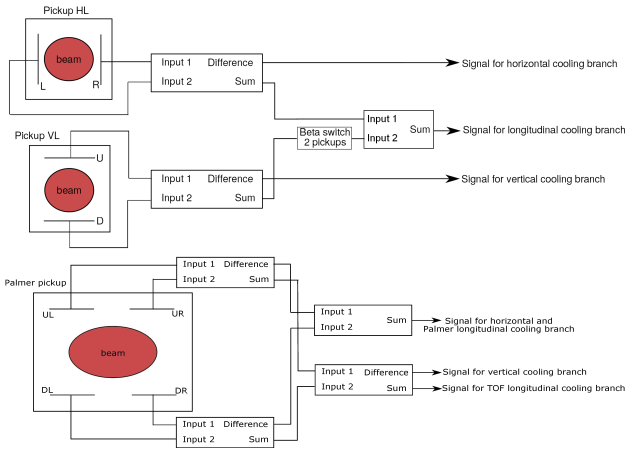

Figure 4: Principle of signal processing for the Palmer and the slotline pickups.

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