STOCHASTIC COOLING IN THE FRAMEWORK OF THE FAIR PROJECT AT GSI *

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Abstract

Stochastic cooling is foreseen in three of the storage rings rings of the FAIR project. This paper discusses new developments for the CR and RESR systems. The system layouts and new hardware developments are presented.

STOCHASTIC COOLING IN THE FAIR PROJECT

Overview

Stochastic cooling at FAIR will be one of the instruments to get cooled beams of rare isotopes and antiprotons for high resolution experiments. Stochastic cooling systems will be installed in the CR and RESR storage rings. The Collector Ring CR is a dedicated storage ring for the first step cooling of antiproton beams (3 GeV,or $\beta = 0.97$) produced at the antiproton production target, and of radioactive beams (740 MeV/u, or $\beta = 0.83$) prepared in the Super Fragment Separator. The pick-up and kicker systems have designs which allow very efficient cooling for both particle velocities. There will be different ring optical settings for optimum cooling of antiprotons or rare isotopes. Whereas the next cooling step for rare isotopes will be electron cooling, antiprotons will be accumulated in the RESR by a stochastic system.

The present design status of the storage rings in the FAIR project is described in [1]. Stochastic cooling in the HESR storage ring has been described elsewhere [2].

CR Stochastic Cooling

The Collector Ring (CR) is a large acceptance ring with full aperture injection. It is built mainly for the initial cooling of the large emittance beams from the Super Fragment Separator or the antiproton target [3], [4]. Before stochastic cooling is applied, the short bunches (50 ns) emerging from the production targets are subjected to bunch rotation followed by adiabatic debunching in order to make the initial momentum spread as small as possible. This is particularly important in case of the rare isotope beams with their relatively large frequency slip factor ($\eta = 0.189$ in contrast to $\eta = 0.015$ for the antiprotons), making undesired mixing a severe problem. There will be four pick-up tanks:

- Three pick-up tanks for the longitudinal, horizontal and vertical signals from antiprotons. These are also used during the final phase of rare isotope cooling.
- The Palmer pick-up tank in the arc for generating the Palmer signal and the transverse signals during the initial phase of cooling of rare isotope beams.

There are three kicker tanks in the non-dispersive straight section opposite to the pick-up side. They are used for both rare isotope and antiproton cooling.

A total microwave power (cw) of 4.8 kW will be installed.

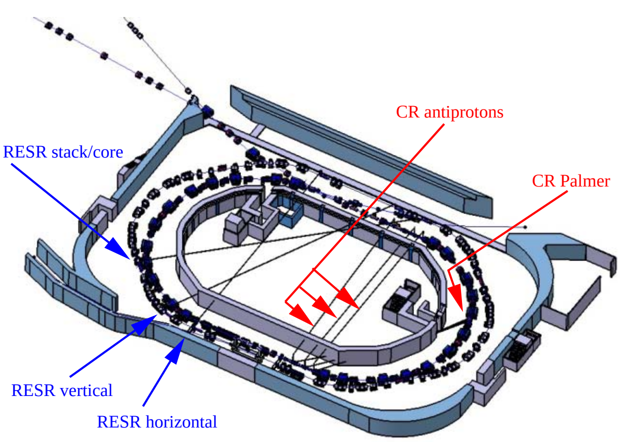

Figure 1: Stochastic cooling paths in the CR and RESR rings

RESR Antiproton Stochastic Accumulation

The antiprototon beams are accumulated in the RESR storage ring [5], [6]. The procedure resembles the ones used at the former CERN AA or the FNAL Accumulator ring [7], [8]. An important condition is to keep the desired mixing parameter

$$M = (m_c \eta \delta p/p)^{-1} \qquad (1)$$

as small as possible. Here m_c is the harmonic of the revolution frequency in the center of the cooling band, and $\delta p/p$ is the momentum width of the beam. Although the latter is not straightforward to define in an accumulation scenario with an exponentially decreasing momentum distribution, first simulation calculations with the lattice described in [6] indicate that the maximum possible $\gamma_t \approx 6.4$ should

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be used (maximizing η). For the dense core a cooling band 2-4 GHz would be beneficial (yielding a large m_c). There are several stochastic cooling systems:

- The tail cooling system which moves the injected beam from the deposition orbit x_d through the stack tail x_t to the stack core and which builds up a distribution increasing exponentially towards the center of the core x_c. Only this system is a high power system (Installed cw power about 1.5 kW).
- The longitudinal core cooling system which keeps the core in place and helps increasing the distribution density at the core.
- A horizontal and vertical core cooling system.
- An optional precooling system could be installed in a later phase of the project in order to enhance the efficiency of the stacking process.

Detailed simulation studies are under way. Whether slotline or Faltin type structures [9] will be installed, is not yet decided.

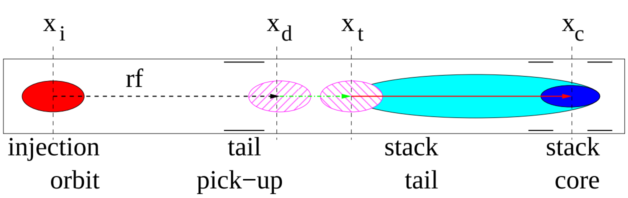

Figure 2: Acumulated beam at longitudinal pick-up

HARDWARE DEVELOPMENTS

Slotline Electrodes

The development of slotline electrodes for the CR has been described in [10]. Figure 3 shows the amplitude and phase of a recent S_{21} measurement between a slotline and an antenna 10 mm above the slot. The frequency response of the device has an excellent broadband behaviour (amplitude $\pm$ 1 dB, phase $\pm 10^0$) that is superior to previous designs such as quarter-wave pick-ups. It should be mentioned that this impedance measurement is only relative. An absolute calibration of the antenna is planned using the well-known field of cylindrical cavity resonators. On the other hand, field theoretical calculations have resulted in impedances per installation length which are larger than those of quarter-wave structures [11].

The present design foresees a cryogenic preamplifier with an effective noise temperature of 10 K for each slotline inside the vacuum tank. This leads to a high signal-to-noise ratio of the pick-up signal. A quantitative comparison of a design as sketched above with a design, where the signal of eight slots is amplified for the first time outside the vacuum tank, yields a signal-to-noise difference of 4.3 dB between the two designs. Therefore the design with cryogenic preamplifiers inside the vacuum should be superior even in case of a failure of half the number of preamplifiers.

Cryogenic Pick-up Tank

A complete mechanical design of a prototype cryogenic pick-up tank has been performed. The call for tenders is presently under way. The tank has a length of 2 m, and it can house a set of two times eight modules as described above, i.e two times 64 slotlines. By a 90 degree rotation of the tank around the beam axis a horizontal pick-up tank is turned into a vertical one, keeping its basic mechanical properties. In order to shield the cold modules ($T < 20$ K) from room temperature radiation, a copper shield at 80 K is installed. It is gilded with a thickness of 4 μm in order to minimize its thermal emissivity, with a thin nickel barrier layer (2 μm) in between preventing degradation of the gold plating due to diffusion processes.

The steel rod which links the cold module with its mechanical drive is thermally coupled to the 80 K shield. At the low-temperature end there is a vespel washer with low thermal conductivity. The modules are cooled by helium cold heads with a total cooling power of 20 W per tank at 20 K. They are driven by small compressor units. As the cold heads are fixed and the modules are movable, the thermal coupling between both is achieved via flexible copper-beryllium sheets (250×10 mm^2). These are 0.1 mm thick and have a thick (50 μm) galvanic silver coating on each

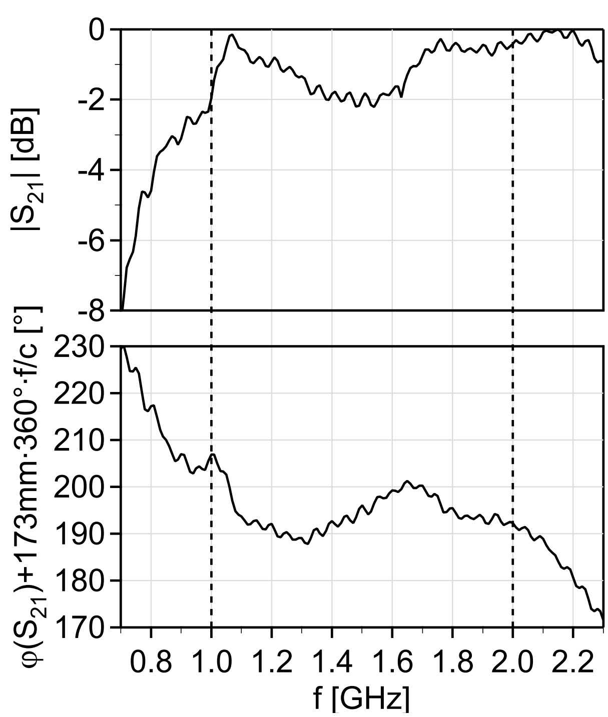

Figure 3: Amplitude and phase of slotline S_{21} test measurement

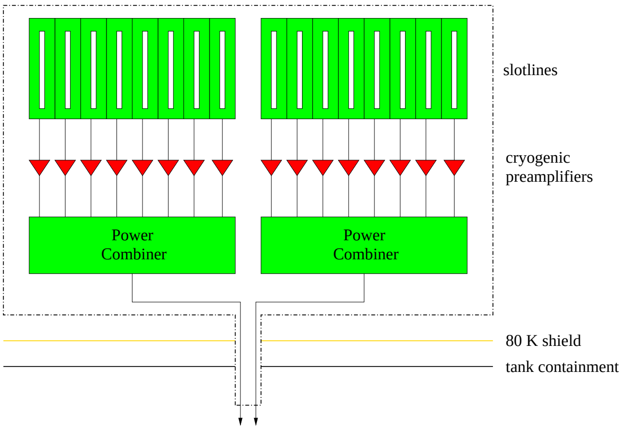

Figure 4: The signal from each slotline is amplified before combining the signal from eight slotlines into a module with a common casing. Two of these modules are attached to one mechanically movable unit.

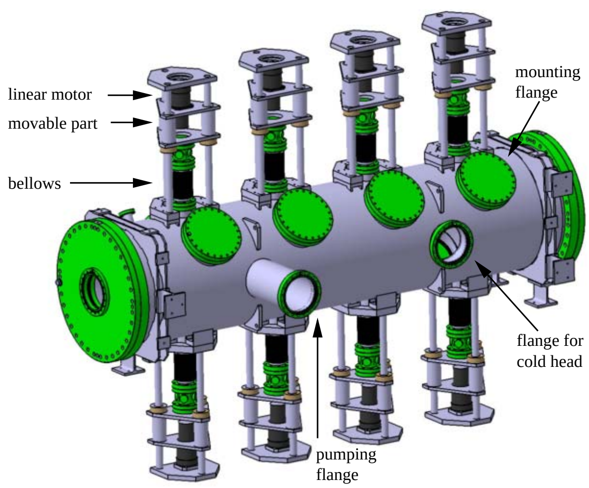

Figure 5: Sketch of pick-up tank with linear motor drives

side to enhance the thermal conductivity.

The microwave signal from each module is connected to a feedthrough flange at the coupling bellows via a hollow coaxial line. A microwave test signal can be coupled to each module from outside. There are also dc signal links into the module for supplying the preamplifiers, or for temperature readout. These dc voltages are transmitted via a capton insulated bus link. Large installation flanges (CF 250) serve for mounting the modules into the tank.

Whereas the power combination of the signals inside each module works with fixed electrical lengths, it is foreseen to switch the power combination outside the vacuum tank of the signals from each module from a $\beta = 0.83$ mode to a $\beta = 0.97$ mode, according to the type of beam which is to be cooled.

Movable Electrode Modules

There are eight modules with 8 slotlines per module on each side of the tank. For each two neighbouring modules there is one mechanical drive. The drives are movable along a distance of 55 mm, following the shrinking beam during cooling. Due to the FODO lattice in the CR, the beta functions vary along the distance in the pick-up tank, making different drive paths beneficial for optimum performance.

The motor is a strong linear servo drive (force 280 N) which is mounted such that it is not subjected to any mechanical abrasion. Springs help the motor work against the vacuum pressure and guarantee a safe park position in case of a motor power failure. The drives are freely programmable. A test stand will be built for testing different jerk-free acceleration profiles.

Power Amplifier

An optimized prototype of the 1-2 GHz power amplifier has been delivered and is presently tested at GSI. The amplitude of S_{21} is constant up to ± 1 dB and the corresponding phase is linear up to 10 degrees inside the working band. Outside the working band the amplification drops by 5 dB before the phase deviates by more than 40 degrees from linear. The amplifier consists of two independent 100 W (at 1 dB compression) units inside a common casing. It is equipped with water cooling.

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