STOCHASTIC COOLING HARDWARE FOR LOW ENERGY DEUTERONS AT COSY

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Abstract

One of the central utilizations of the COSY facility nowadays is to host experiments for the JEDI (Jülich Electric Dipole moment Investigations) collaboration. These experiments use polarized deuteron beams at momenta below 1 GeV/c, that are stored for several minutes. In order to increase the spin coherence time, beam cooling is necessary. Electron cooling is applied to pre-cool the beam, but the solenoids of the electron cooler may not be perfectly compensated. Thus, stochastic cooling would be desirable instead. Unfortunately, the existing stochastic cooling system is not sensitive at low beam velocities.

This paper presents newly developed stochastic cooling pickups and kickers for a system dedicated to low beam velocities of approximately 0.5 c. The design is based on the slot-ring type pickups that have been developed for the High Energy Storage Ring (HESR), but optimized for low particle velocities and a low frequency band of 350-700 MHz. Since the structures get much bigger in comparison to the HESR version, mechanical properties must be reconsidered and a trade-off between electrical properties, cooling performance and constructability must be found.

BEAM COOLING AT THE COSY FACILITY

The Cooler Synchrotron (COSY) of Forschungszentrum Jülich [1] started its operation in 1993. The 184 m long racetrack synchrotron accelerates and stores protons and deuterons in a momentum range of 0.3 to 3.4 GeV/c. Remarkable features are polarized sources for both protons and deuterons, two electron coolers, and a stochastic cooling system.

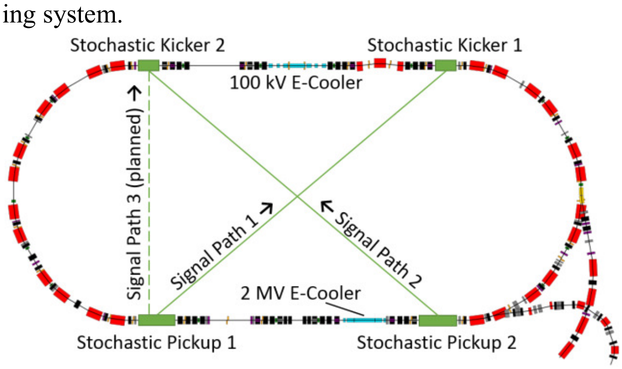

Figure 1: Floor plan of COSY, with the two electron coolers and the stochastic cooling system.

The first e-cooler has a maximum electron energy of 100 keV, with a typical beam current of 250 mA [2]. It can cool protons with a momentum up to 0.6 GeV/c, or deuterons up to 1.2 GeV/c. In 2013, a second e-cooler was installed. It covers a wide electron energy range from 0.025 to 2 MeV [3].

The original stochastic cooling system is meanwhile out of service and partially disassembled to make space for new systems. It was installed at the positions shown in Figure 1 and consisted of quarter-wave couplers that could be plunged to have a large aperture at injection, and a better signal to noise ratio at high energies. The vertical and longitudinal planes were covered by the system labelled "1", the horizontal plane by system "2". The pickup tanks had a length of four meters and were cooled to 30 K to reduce thermal noise. The kicker tanks were two meters long. The system worked in two frequency bands, i.e. 1 to 1.8 GHz and 1.8 to 3 GHz. It was capable to cool particles with momenta above 1.5 GeV/c [4].

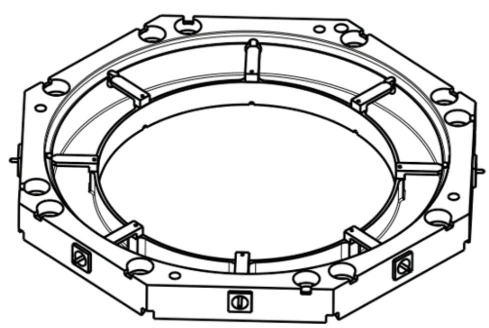

Figure 2: Technical drawing of a single slot-ring for the HESR stochastic cooling system.

Today, the space is partly used for the stochastic cooling system [5] of the High Energy Storage Ring (HESR) [6]. This newly developed system works in a 2 to 4 GHz band. It consists of slot-ring couplers that interact with the magnetic field of the beam (Figure 2). Each slot-ring is equipped with eight electrodes, i.e. two pairs for the horizontal and two for the vertical plane. The sum signal of all eight electrodes is used for longitudinal cooling. Thus, all three planes can be cooled simultaneously with one single structure. The signal of each electrode is led via a 50 Ω connection to a combiner board directly attached to the rings. In that manner, a stack of 16 rings is combined hardwired. A tank contains four such stacks, whose signals are added outside the tank with a beam energy dependent adjustable delay.

The new design unites two advantages. First, the sensitivity is sufficient despite the static aperture. Thus, no movable parts are needed. Second, due to the high sensitivity and the simultaneous cooling of all three planes, the tanks

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get much shorter. The first pair of pickup and kicker is installed at COSY for testing and utilization until it can be moved to HESR. Due to the 3D-cooling, only line 1 in the floor plan is needed. Furthermore, the new pickup tanks only need roughly half as much space as the old devices, leaving free space at the beam pipe for other installations.

REQUIREMENTS OF JEDI EXPERIMENTS

The JEDI collaboration aims at measuring the potential permanent electric dipole moment (EDM) of hadrons by investigating polarized beams in storage rings [7]. At COSY, polarized deuterons are stored at a momentum of 970 MeV/c. To achieve the needed level of sensitivity for finding an influence of the EDM on spin motion, high coherence times for the spin precession in the order of 1000 seconds are needed [8]. By pre-cooling with the e-cooler, polarization lifetimes of several seconds could be achieved [9].

A drawback of e-cooling polarized beams lies in the polarizing property of its solenoid magnet. Although the solenoid is compensated by two additional magnets next to the cooler, it is a source for additional errors and therefore undesirable for high precision experiments. Stochastic cooling, otherwise, has no need for additional focusing elements. Unfortunately, neither the old COSY system nor the new HESR system are sensitive at such low particle velocities. Therefore, we started to evaluate a dedicated stochastic cooling system for slow particles.

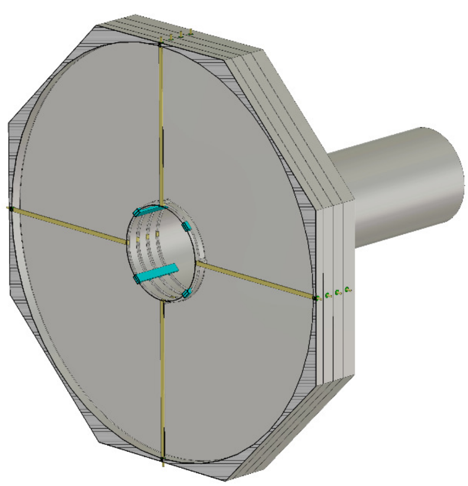

Figure 3: Proposed pickup and kicker hardware for low beta beams.

STOCHASTIC COOLING OF LOW BETA BEAMS

Deuterons with a momentum of 970 MeV/c have a velocity of $\beta = 0.46$. The combiner boards of the HESR stochastic cooling system are optimized for $\beta = 0.93$. Therefore, the combination loss is more than -13 dB at the given velocity in the 2 to 4 GHz band. Furthermore, as the single rings of the HESR system have a poor sensitivity for slow particles, the currently installed system is not suited for EDM experiments.

Since the HESR cooling system it is much shorter than the deprecated system, there is space for a second system, dedicated to low beta beams. We decided to use the same slot-ring type structures as for HESR, because of its compactness, as well as the in-house experience in design and manufacturing of such structures.

The existing signal path 2 in Figure 1 is the obvious choice for the new system. Yet, we decided to install a new line, labelled "3" in the floor plan, which connects pickup 1 and kicker 2. This is because of the neighbourhood of pickup 2 and the injection point. For the HESR system, the aperture is locally reduced from 150 mm to 90 mm. This is beneficial for the new pickups and kickers as well, because it significantly increases the sensitivity. At injection, the full 150 mm aperture is needed. But at pickup position 2, it is already reduced by the HESR system. Furthermore, there is still sufficient space because of the small length of the HESR pickup.

The new signal path is possible, because the straights of COSY act as 1-to-1 telescopes. Thus, the phase advance of the beta-function is the same at both kicker positions. Furthermore, the time-of-flight of a particle with $\beta = 0.46$ from pickup 1 to kicker 2 is still longer than the time the signals need to propagate along line 3. Consequently, the particles can be manipulated by their own signal of the same revolution, which is a necessary condition for beam cooling.

The frequency band was set to 350 to 700 MHz. System simulations showed that the used frequency band must stop below 800 MHz to avoid Schottky band overlap. Besides, the low frequencies are very beneficial for high pickup and kicker sensitivity as well.

DESIGN OF NEW PICKUP / KICKER HARDWARE

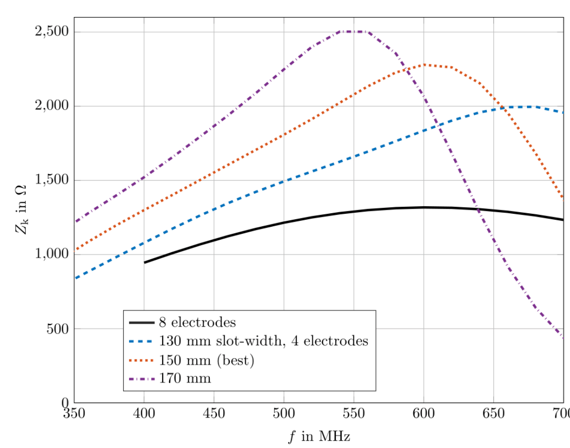

Figure 4: Longitudinal shunt impedance of different 64-cell kickers.

Starting from the HESR geometry, the slot-rings were optimized for high longitudinal shunt impedance. Therefore, kickers have been simulated with CST Microwave Studio 2016 [10]. By varying different parameters like slot-width and cell height, a geometry with a sufficiently high impedance in the desired frequency band was found. Figure 3 shows a cut through the transverse plane of the final structure.

In Figure 4, the shunt impedance of a 64-cell structure with the final design is shown and compared to some variations. The most sensitive parameter is the slot-width, which tunes the optimum frequency in the desired band. Since this leads to very huge structures, some mechanical properties had to be adjusted. The thickness of the base plates was increased for a better stiffness. Supports made of polyether ether ketone (PEEK) have been inserted between the single rings to fix the distance, and sleeves in the coaxial connectors centre the long electrodes.

The height of the single cells has a strong effect on the shunt impedance as well. Slimmer cells lead to lower impedances per cell, but in comparison to the length of the structure, the sensitivity increases. Yet, very slim cells are not reasonable, since the combiner boards get more complex and lossy. For a trade-off, 12.5 mm was chosen.

Furthermore, the number of electrodes per ring was reduced from eight to four. More electrodes increase the bandwidth of the structure, but reduce the peak sensitivity. Nevertheless, as can be seen in Figure 4, four electrodes still lead to higher impedances along the whole band.

Although the structure was optimized for longitudinal performance only, the transverse shunt impedance of the 64-cell structure turned out to be better than 1.6 kΩ in the whole band. This is sufficiently large for an efficient transverse cooling. Consequently, the structure was not further optimized to find a better trade-off between longitudinal and transverse performance.

ANTICIPATED PERFORMANCE

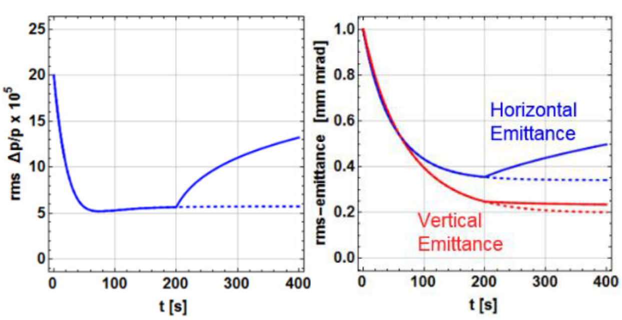

Figure 5: Simulation results of momentum spread (left) and emittances (right) during cooling. After 200s, cooling is turned off.

The cooling performance of the proposed system was simulated for an EDM beam consisting of 10^9 deuterons. For the simulations, intra-beam scattering was considered. For the longitudinal case, filter cooling was assumed. Figure 5 shows how the rms momentum spread and the rms emittances evolve in 200 seconds of cooling. The longitudinal time constant is approximately 30 s, the transverse 80 s. The equilibrium states are $6 \cdot 10^{-5}$ for momentum spread, and 0.35/0.2 mm mrad for horizontal and vertical emittance.

After 200 s, the cooling is turned off. The beam grows again due to intra-beam scattering. Thus, instead of pre-cooling only, an operation during the whole experiment would be desirable. We already investigated the influence of stochastic cooling on polarized beams in the past at higher energies [11], and couldn't observe any depolarizing effects. Therefore, we are hopeful that cooling even during the experiments is possible.

Another important result of the simulation is the amount of RF power required. It turned out that off-the-shelf 5-watt power amplifiers are sufficient for the system. This is very beneficial, since power amplifiers are usually an important matter of expense in stochastic cooling systems.

OUTLOOK

A small number of rings will be built in the next couple of month to test the construction. If the stiffness of the structure is sufficient and the plates do not warp during the milling process, all feasibility studies are completed and the construction of the tanks can begin.

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