RF AND STOCHASTIC COOLING SYSTEM OF THE HESR

R. Stassen, F.-J. Etzkorn, G. Schug, H. Stockhorst, Forschungszentrum Jülich, Germany
T. Katayama, Tokyo, Japan, L. Thorndahl, Geneva, Switzerland

Abstract

The High-Energy Storage Ring HESR (1.5-15 GeV/c) for antiprotons at the FAIR complex (Facility for Antiprotons and Ion Research) in Darmstadt (GSI) will have a dedicated stochastic cooling system not only during the experiments to fulfill the beam requirements, but also during the accumulation due to the postponed RESR. Here the cooperation of stochastic cooling with different barrier-bucket configurations is necessary for high accumulation efficiency. The latest hardware configurations and recent tests results of both the RF-system with air-cooled cavities and the stochastic cooling based on slot-ring couplers will be presented.

The RF-System

The RF-system of the HESR will consist of two identical cavities with a common low-level RF control (LLRF). Both cavities will be driven by solid state amplifiers. Each cavity contains of one gap and two tanks operating in push-pull mode. Each tank will house 6 ring cores wound of modern magnetic nano-alloy ribbon. Each ring will have a separate coupling loop, and every two rings will be combined. This coupling scheme shows the advantages that the combination of two cores connected to one amplifier gives the best matching condition for all operation modes. The influence of the parasitic elements of the rings is reduced and the individual compensations of the rings reactances lead to a higher bandwidth compared to the usual gap coupling. The rings will only be selected in pairs. Main parameters of the HESR RF system at different operation modes are summarized in Table 1.

Table 1: HESR RF Stations

No of cavities	2 (identical cavities with common LLRF to allow a moving barrier-bucket operation)
HESR revolution frequencies	440 kHz … 520 kHz
Frequency-range	1-20 harmonics (0.4 … 10 MHz)
Gap voltage: Accumulation Acceleration Experiment Max. Gap voltage At a max. Duty cycle	 +/- 2500V Barrier-Bucket, f_{BB} ~ 5MHz, pulsed (1:10), moving barrier by second cavity +/- 1000V dual harmonic, CW +/- 1000V Barrier Bucket, f_{BB} ~ 2.5MHz, CW 2kV up to 4kV 100% down to 20%
Amplifier	12x 1 kW solid-state amplifiers

The HESR is proposed to be used also as accumulator ring because storage-ring RESR in the FAIR-project [1] is postponed. A dedicated concept has been worked out and simulated [2]. Stochastic stacking as used at CERN or FNAL [3] is not possible without changing the whole layout and parameters of the HESR and requires the installation of an additional stochastic cooling system. Instead of this the proposed RF-system and stochastic cooling system has been slightly changed to allow an accumulation scheme where a barrier bucket cavity separates the stored cooled beam from the new injected particles. One major change is the new LLRF-system synchronized with the Bunch Phase Timing System (BuTiS) [4].

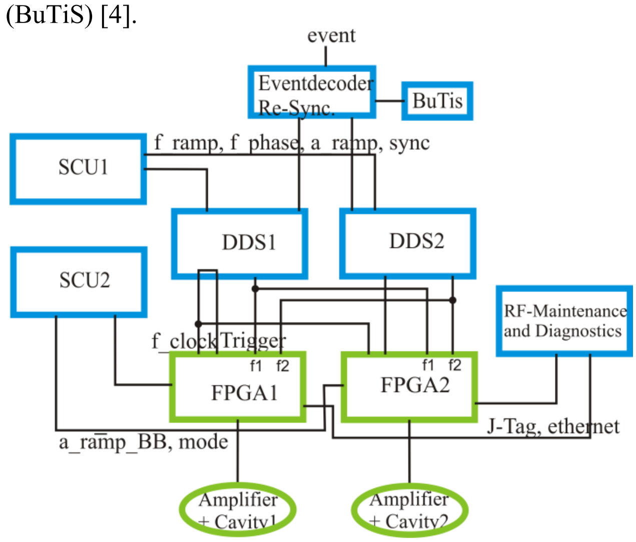

Figure 1: low level RF system: SCU1, SCU2 standard control units, DDS1, DDS2 Direct digital synthesiser, FPGA1, FPGA2 field programmable gate.

Two standard DDSs (direct digital synthesizer, designed for all FAIR-RF systems [5]) deliver the clock and trigger signals for FPGA-based RF-generators. Pre-distorted signals to generate different single sinus barrier bucket voltages at the RF-gap as well as the acceleration and deceleration waveforms will be stored in files. Tests of the digital phase-locked loops in modern FPGAs have shown that clock-signals from the DDS can be used to generate the sample-frequency internally even if the frequency change is a factor of three as performed at COSY [6]. Thus the accelerator COSY can be used to test all relevant operation modes with real beam.

The ring cores will no longer be cooled by water but by air. That increases the impedance and thus reduces the required RF-power. Every two cores will be cooled by an intermediate nonmetallic cooling disk. Both sides of the disk contain radial slots as orifices of free planar air jets. The density of these slots has regard to both the inhomogeneous RF loss power density and the poor radial thermal conductivity of the ring cores due to the insulation between the ribbon layers. The cooling capability per cavity amounts to 1.5 kW at an air flow of 600 l/s at 50 m/s. The resulting local temperature rises of the magnetic material keep within 70 K. Most prototype

ISBN 978-3-95450-115-1

components have been manufactured and first cooling and RF-power tests are expected in 2012.

Stochastic Cooling Tanks

The system design is finished now including additional simulations [2] and system extensions to fulfill the requirements during the accumulation process. The main system of the HESR stochastic cooling (SC) system will operate in the frequency range from 2-4 GHz. In total, 5 SC-tanks will be installed, each tank housing 64 slot coupler rings and each ring is coupled out by eight electrodes [7]. Two tanks will be used as pickups, each cryogenically cooled by two cold heads on top of the tank. The mechanical layout of the cooling structure has been changed. Support bars and rings connect the combiner-boards now with the second stages of the cryo-pumps. Thus the lowest temperature of about 20 K will be found at the Wilkinson resistors which are the main noise sources. The inner part of one pickup tank including all combiner-boards is shown in Fig. 2.

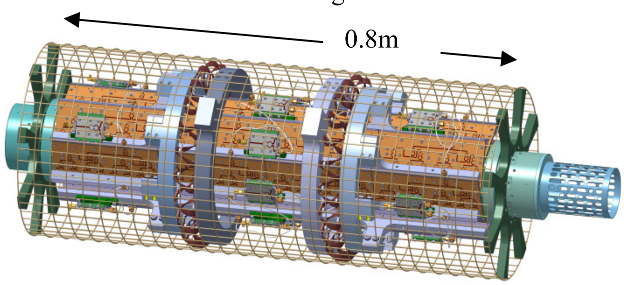

Figure 2: Inner part of one pickup tank with combiner-boards and supports for the cryogenic connections.

Each pickup will be used to detect the signals of all three cooling planes (horizontal, vertical and longitudinal) at the same time. Extensive measurements at COSY [8] with proton-beams in 2008 and 2009 have shown that the vertical and horizontal betatron sidebands can be separated although the structure has a continuous slot around the beam. No unwanted coupling between the horizontal and vertical plane has been found (Fig. 3).

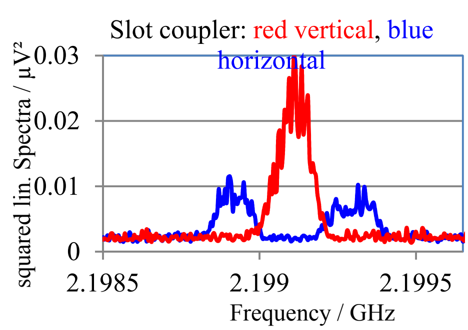

Figure 3: vertical and horizontal betatron sidebands measured with the same structure. The vertical sidebands merge together because the tune Q_y was close to 3.5.

Meanwhile two slot-ring structures with stacks of 16 rings have been installed into the Nuclotron in Dubna [9]. The system is nearly prepared now for first stochastic cooling tests in Dubna with the new structures.

Signal Combination

16:1 combiners - optimized for a best signal combination at injection energy (ß = 0.96) - join the electrodes in beam direction and built the smallest group without active change of signal delay. The combiner losses at lowest HESR energy and hereby the degradation of the signal-to-noise ratio are in the order of 2.5 dB which is still tolerable (Fig. 4).

2:1 combiners join neighboring electrode-rows to get the upper, lower, right and left signals for the transverse cooling. These combiners are designed as heat traps for the heat flow coming from the RF lines.

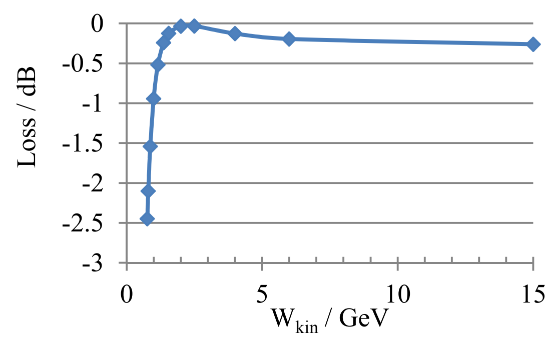

Figure 4: Losses of the 16:1 combiner at different energies. The shown losses are upper limits occurring at 4 GHz.

The pre-amplified signals will be combined in further 3 layers (Fig. 5). Hereby, switchable delay lines are required to compensate for the energy-dependent beam drift time. The delay lines will be switched in steps of 10 mm of electrical length at the first layer (PV1) and 20 mm at the further layers (PV2, PV4).

Each programmable delay-line includes a Wilkinson coupler which combines the two input signals after the switching stage. A deviation of 10 mm from the ideal length leads to a phase difference between the Wilkinson inputs that causes at 4 GHz an additional attenuation of nearly 0.8 dB. The last Wilkinson layer adds the power of both adjoining tanks. This allows stochastic cooling in the whole energy range of the HESR (0.8 - 14 GeV). To minimize the number of switches, the reference plane is shifted at different energies but this can be easily compensated by adjusting the delay-line between pickup and kicker. Further, each signal-path of the delay-lines contains the same number of switches, and has therefore a similar amplitude-frequency characteristic. This reduces the expense of its compensation. Prototypes of each delay line were built and tested and fulfilled all RF requirements.

The kicker-tank layout will be similar to the pickup-tank layout except that no cryogenic cooling system will be installed and the electrode combination within the tank and thus the number of feed troughs will be adjusted according to the RF power needed for the new accumulation scheme [10]. Here, three tanks will be installed, one for each cooling direction. Nevertheless, all tanks will be fully equipped to ensure that each tank can be used for any cooling plane. This gives a good compromise to meet the necessary phase advance at the different foreseen optics. During the accumulation, all tanks will be used for longitudinal cooling, where a higher RF power is needed. A relay-matrix will be used to switch between the different operations modes. This concept provides an installed RF power of about 250 W for each transverse cooling direction (horizontal/vertical) at each tank, or 500 W per tank when used for longitudinal cooling.

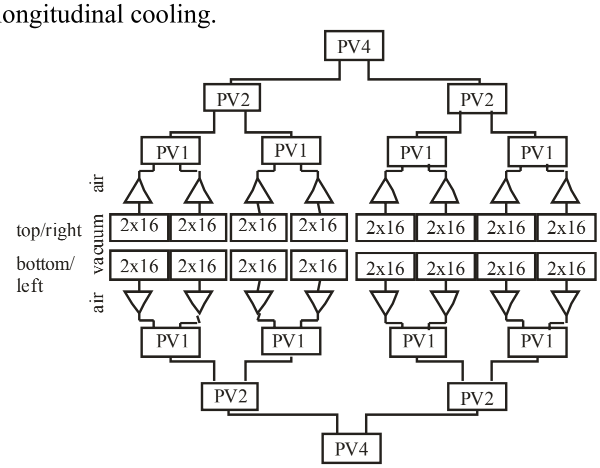

Figure 5: Pickup section with programmable delay-lines (PV) to provide stochastic cooling in the whole energy range of the HESR (lengths are not to scale).

Power Amplifier

A significant emittance reduction requires high power amplifiers in the active cooling chain. Power amplifiers in the 2-4 GHz range are nowadays commercially available. But the specific requirements concerning group-delay and phase behavior demands a particular design. The GaN technology plays an important role in the present and future development of high-power broadband amplifier and shows advantages for our special requirements. A first prototype of a 25 W amplifier was built in collaboration with IMST [11]. All required parameters have nearly been reached but the modular design with separately housed stages showed some restrictions. The final version will have a compact one-board design with separated caves for each GaN transistor similar to the design of the delay lines.

Signal Transmission and Optical Notch-Filter with Active Frequency Control

Two longitudinal cooling methods will be used at the HESR: TOF-cooling (Time Of Flight [12]) as pre-cooling system and when a sufficient beam spread is reached, the powerful Notch-Filter cooling. Both signal paths of the notch-filter will operate in the optical range. This eliminates phase noise and amplitude variation from the laser. Typical data for the HESR are:

$\eta \sim 0.06$; $\Delta p/p \sim 2E\text{-}5$ $\quad\Rightarrow \Delta f/f \sim 1E\text{-}6$

Thus the fluctuations of each notch frequency over the time must be within 0.5 Hz. A temperature control in the order of 0.1K would be necessary taking into account the high temperature sensitivity of the fibre-optic delay lines (30 ps/km/K). A much better solution has been found by an active control of the notch frequency. Besides the signal from the pickup, a fixed frequency pilot signal will be added and transmitted through both optical paths. Directional couplers after the photo-detectors take band-pass-filtered parts of the transmitted signals to a phase detector. Any differences between the lengths of the two signal paths and thus any change of the notch frequencies will be detected by the phase detector. The controller closes this active loop by driving the fibre optic delay line according to the phase change of the pilot signal. The prototype of the notch-filter has been used to measure the frequency change of the 7100th harmonic over one night, which was in the order of 150 kHz or corresponding to the HESR revolution frequency 25 Hz. The frequency change was completely compensated by the phase loop after closing the control-loop. Within the accuracy of the networkanalyser, no frequency change has been measured. A similar system will be used to control the optical fibre link from pickup to kicker by using the BuTis (bunch phase timing) system to generate a phase stable pilot signal at the kicker side.

REFERENCES

[1] FAIR Technical Design Report, GSI Darmstadt, 2008.
[2] H. Stockhorst, R. Maier, D. Prasuhn, R. Stassen, Status of stochastic cooling Predictions at the HESR, Proceedings of IPAC11, San Sebastian, Spain, 2011.
[3] F. Caspers and D. Möhl, Stacking with Stochastic Cooling, CERN-AB-2004-028 RF.
[4] P. Moritz, BuTiS – Development of a Bunchphase Timing System, GSI Scientific Report, 2009.
[5] K.-P. Ningel et al., Dual Harmonic Operation at SIS18, Proceedings of IPAC10, Kyoto, Japan, 2010.
[6] R. Maier, Cooler Synchrotron COSY – performance and perspectives, NIM A 390 (1997) 1-8.
[7] L. Thorndahl, 90mm Full-Aperture Structures with TM01-Mode propagation for 6-8 GHz Stochastic Momentum Cooling in HESR, internal report, 2010.
[8] R. Stassen, et al. COSY as ideal Test Facility for HESR RF and Stochastic Cooling Hardware, Proceedings of PAC09, Vancouver, Canada, 2009.
[9] G. Trubnikov et al., Project of the Nuclotron-based ion collider facility (NICA) at JINR, Proceedings of EPAC08, Genoa, Italy, 2008.
[10] T. Katayama, T. Kikuchi, R. Maier, I. Meshkov, D. Prasuhn, R. Stassen, M. Steck, H. Stockhorst, Beam accumulation with barrier voltage and stochastic cooling, Proceedings of IPAC10, Kyoto, Japan, 2010.
[11] IMST, www.imst.de Kamp-Lintfort, Germany.
[12] H. Stockhorst, R. Stassen, D. Prasuhn, R. Maier, T. Katayama, L. Thorndahl, Compensation of mean Energy Loss due to an internal Target by Application of a Barrier Bucket and Stochastic Momentum Cooling at COSY, COOL09, Lanzhou, China, 2009.

ISBN 978-3-95450-115-1