FIRST EXPERIENCES WITH HESR STOCHASTIC COOLING SYSTEM

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Abstract

The stochastic cooling system of the HESR (High Energy Storage Ring) is based on completely new structures especially designed for the HESR. Each beam surrounding slot of these so called slot-ring couplers covers the whole image current without a reduction of the HESR aperture and without any plunging system. One pickup (PU) and one kicker (K) system have been already fabricated and installed into the COSY ring to demonstrate stochastic cooling in all three dimensions with only one structure. First results of commissioning with proton beams will be presented. The longitudinal cooling system at HESR is based on filter cooling with an optical notch-filter and ToF cooling. The demanding accuracy concerning phase stability requires dedicated control of the notch-frequency. The optical COSY filter has been modified and can be proven in long term runs together with the new stochastic cooling system.

STOCHASTIC COOLING SYSTEM OF HESR

Stochastic cooling at HESR is not only used to reduce beam size and momentum spread during the experiment, but also to accumulate antiprotons due to the postponed Recuperated Experimental Storage Ring (RESR) [1, 2] of the modularized start version of the FAIR project.

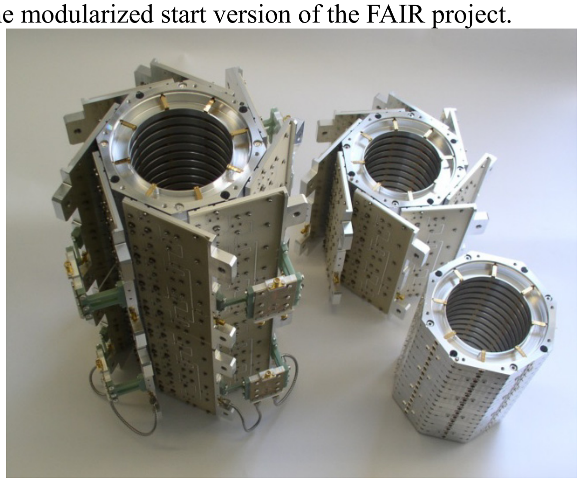

Figure 1: Stacks of slot ring couplers with and without 16:1 combiner-boards and two stacks mounted together including 2:1 combiner with heat-trap.

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]. Each resonant ring structure is heavily loaded with eight 50 Ω electrodes for a broadband 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. Fig. 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.

Basic parameters of the main 2 - 4 GHz system are summarized in Table 1.

Table 1: Parameters of the Main Stochastic Cooling System

Main system	**Based on slot-ring couplers**	
Bandwidth	2 - 4	GHz
Cooling methods	transverse, longitudinal filter cooling, longitudinal ToF cooling	
β-range	0.83-0.99	
Pickup:	**2**	**tanks**
No. of rings /tank	64	
Shunt impedance Z_{pu} / ring	9	Ohm
Total impedance	1152	Ohm
Structure temp.	20	K
Kicker:	**3**	**tanks**
	2 tanks for transverse **or** longitudinal cooling, 1 tank longitudinal cooling only	
No. of rings /tank	64	
Shunt impedance Z_k / ring	36	Ohm
Impedance /tank	2304	Ohm
Installed power/tank	640 (longitudinal cooling) 320 (transverse cooling)	W W

The same system will be used to cool also heavy ions. Extensive simulations have shown that gain and installed RF-power are sufficient to cool $1*10^8$ heavy ions (limited due to radiation safety) above 740 MeV/u [4].

Pickup Installation

The COoler SYnchrotron COSY [5] at the Forschungszentrum Jülich is operating now since 1992. Up to $5*10^{10}$ protons can be delivered over a momentum range of 300 MeV/c to 3.7 GeV/c. The flexible optics and different beam manipulation techniques qualified COSY as ideal test-bench for HESR hardware like stochastic cooling, barrier bucket cavity or beam position monitors [6].

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The first HESR series pickup was installed into COSY during the winter-shutdown 2015/2016 and is used to measure routinely Schottky spectra for several experiments (Fig. 2).

Two cryo-pumps are installed to cool down the pickup and increase the signal to noise ratio. 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 $5*10^{-10}$ mbar.

Figure 2: Installation of first HESR pickup tank in COSY.

During the beam-time in September 2016 Schottky spectra of each output in the frequency range 1.5 – 4.5 GHz were taken. The following figure presents the transverse sidebands measured with only $8*10^8$ particles.

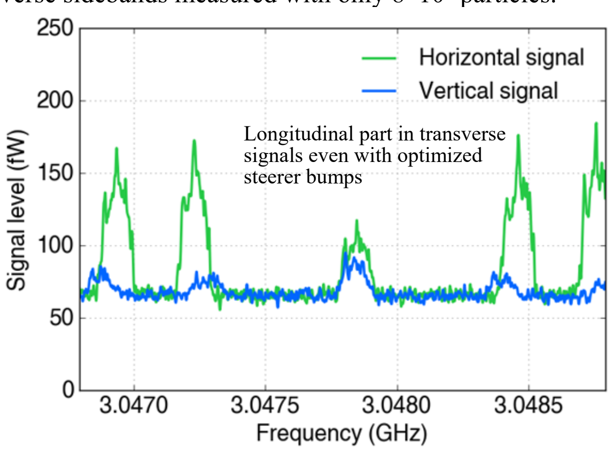

Figure 3: Transverse sidebands with $8*10^8$ particles.

The signals have different amplitudes due to different beam sizes and different betatron-functions in vertical and horizontal directions. Although the beam was centred according to the structure a remaining longitudinal part is clearly visible in both planes.

Each single output of the various groups has been measured in the whole frequency range. The signal combinations including the programmable delay-lines to cover the whole HESR energy range was successfully tested.

Kicker Installation

During the summer shutdown 2016 the first HESR kicker tank was installed in COSY at the position of the old vertical kicker (Fig. 4).

First commissioning started in February 2017 after installing the new notch-filter, measurement system and prototype of the GaN power amplifier.

The automated frequency adjustment of the notch-filter was successfully tested and takes less than a minute for frequency and gain - whereas with the old system the typical setup time was in the order of one hour. The program determines also the frequency error for each notch with respect to the fundamental frequency. The fluctuations of the Notch-frequency were within +/- 10 Hz taking into account the harmonic number. This is pretty small and does not influence the cooling time and power, but can still increase the equilibrium momentum spread due to the small eta-value in the HESR. These fluctuations are dominated by the transimpedance amplifiers in the optical receivers and can be further reduced by pairing the receivers.

Figure 4: First HESR kicker installed at COSY.

The algorithms for automatic open-loop measurements and system delay adjustment were also successfully tested and refined. The open-loop measurements now can be carried out for the full bandwidth within single sweep or by separate measurements of each harmonic. The latter had a problem of random phase jumps near ±180°, which made it impossible to calculate phase in the center of the harmonic. The problem was solved with the fairly simple trick: for each harmonic the algorithm iteratively finds (by minimizing the standard deviation) the artificial delay that would shift the phase to zero, then it calculates the phase and restores the phase to its original value.

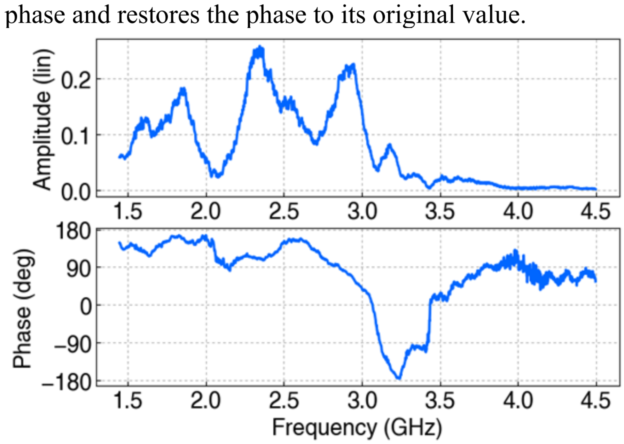

Figure 5: Amplitude (top) and phase (bottom) of system's hardware transfer function.

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A lot of open-loop measurements were performed during first commissioning. The relative hardware transfer function from PU to K - derived from these open-loop measurements – is plotted in Fig. 5. Regions with high amplitude and good phase behaviour alternate with good phase and smaller gain and above 3 GHz with strong phase change and very low amplitude. The reason for this strange behaviour was found in a wrong orientation of the kicker with respect to the beam direction. Simulations of a rotated structure with CST Microwave Studio [7] have shown a similar behaviour.

Nevertheless first longitudinal cooling has been carried out using the ToF [8] cooling method (Fig. 6) and filter cooling (Fig. 7). The beam was initial heated and the particle numbers was about $N = 1*10^9$. Figures 6 and 7 show one longitudinal Schottky spectrum at about 3 GHz (blue: before cooling, green: after several minutes of cooling).

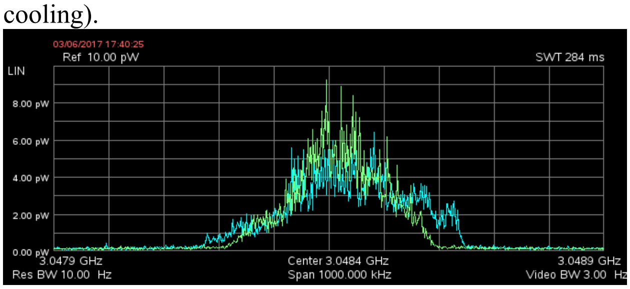

Figure 6: Longitudinal cooling with ToF method.

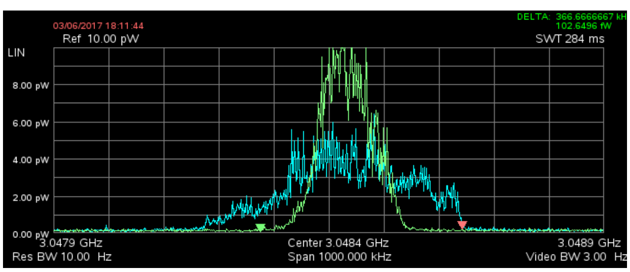

Figure 7: Longitudinal cooling with Filter method.

The 180° phase shift between ToF and filter cooling was realized by adding a delay of 130 ps instead of an additional 180° phase shifter.

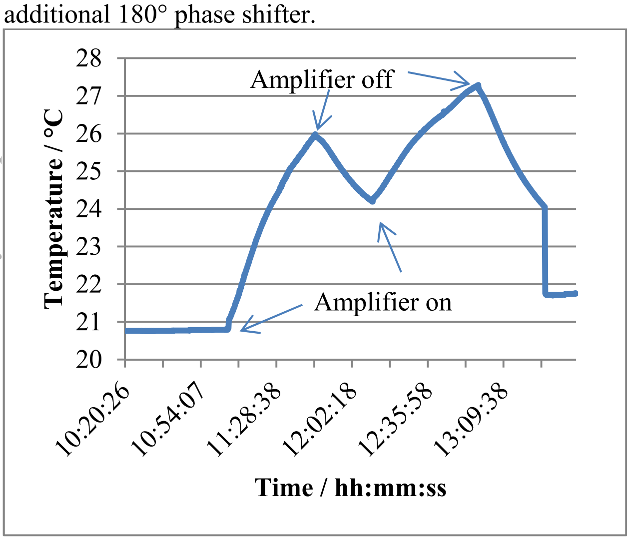

Figure 8: Temperature at combiner-board.

Due to the small amplitude above 3 GHz the cooling works like a system with reduced bandwidth. Cooling simulations show similar cooling times when the measured hardware transfer function is included into the simulations.

Most of the RF-power will be dissipated by the Wilkinson resistors on the combiner-boards. Each combiner-board is connected to a fixed water-cooled pipe by thick copper ribbons.

Highly gained noise from the pickup was used during the first kicker test to drive the 80W power amplifier into saturation (worst case scenario). The temperature on one of the four driven combiner-boards increased only from 20.8°C to 27°C within 40 minutes, but without reaching equilibrium (Fig. 8). When the amplifier is switched off the temperature decrease rate is in the same order. Thus the heat flow to the water cooling pipe is not as high as expected. In order to increase the heat flow from combiner-board to the aluminium support structure the combiner-boards will be additionally glued with a special heat conductive and electro conductive glue already tested for the HESR vacuum requirements.

OUTLOOK

The construction of the whole kicker tank is absolutely symmetric, even the mounting feet. Thus the tank has been easily rotated and reinstalled during the last shutdown. Next cooling beam-times are expected for the second half of 2017 where – with the now right orientation of the kicker tank – full longitudinal as well as transverse cooling can be demonstrated.

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