# DEVELOPMENT OF STOCHASTIC COOLING TECHNIQUE FOR NICA PROJECT

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*Abstract*

Joint Institute for Nuclear Research (JINR) initiated the creation of a new and unique heavy-ion collider – Nuclotron-based Ion Collider Facility (NICA), which is planned for commissioning in 2016. The luminosity in the colliding beams of gold ions is expected to reach $10^{27}$ $cm^{-2}s^{-1}$. By estimations the luminosity will be mainly determined by the intra-beam scattering effect. To suppress this, a cooling system should be used. For the medium and high-energy heavy ions such as at NICA collider, stochastic cooling will be more efficient than electron cooling, so that system will be used in the collider. It was decided to construct a prototype stochastic cooling system, which can be tested at the Nuclotron in an early stage of the NICA project. A longitudinal stochastic cooling system was constructed in 2011. The report presents first experimental measurements and further developments of the stochastic cooling system.

## INTRODUCTION

JINR is in the initial phase of constructing the NICA collider [1] for which both longitudinal and transverse stochastic cooling systems are obligatory. We are developing the stochastic-cooling system of NICA at the existing Nuclotron superconducting synchrotron at JINR. So, we gain experience of stochastic cooling in a NICA-specific environment [2]. The prototypes has been designed and tested during the years 2010 and 2011. The experiment with this constructed stochastic cooling system was carried out in November 2011. In the course of the experiment, longitudinal Schottky noise and beam transfer function were measured and the optical notch-filter was tested. Since experiment the scheme of the system was significantly developed and improved. The results of the experiment as well as new system design will be discussed below.

## EXPERIMENT SETUP AND RESULTS

Main parameters of the accelerator and the cooling system are summarized in Table 1.

Table 1: Parameters of cooling system

| | |
|---|---|
| Circumference, m | 251.5 |
| Ions | Deuterons, C6+ |
| Energy, GeV/u | 0.5-4 |
| Rev.frequency, MHz | 1.13 |
| Number of particles | $10^9$ |
| Momentum spread, Δp/p | $10^{-3}$ |
| Ring slip factor | 0.0322 |
| System bandwidth, GHz | 2 - 4 |

The first step of the realization of the stochastic cooling experiment was longitudinal cooling of coasting beam. The dispersion value is too small in the section, where the pick-up is placed, so Palmer method cannot be implemented. Instead a scheme with a notch filter was installed. The octave band of 2-4 GHz was chosen for that system. The scheme of the system is shown in Fig. 1.

Slot ring couplers, developed and produced at FZ Juelich [3], were used for pick-up as well as for kicker. Both structures have identical design – an assembly of 16 rings with 8 electrodes each. Longitudinal coupling impedance of each ring is 9 Ohms. The pick-up is placed in a cryostat at 10 K, while the kicker is placed at room temperature. Each output of pick-up has a 34 dB low-noise pre-amplifier. The outputs are then combined together. The optical notch-filter [4, 2] was adjusted for 2 GeV deuteron beam; the notch depth was not less than 35 dB.

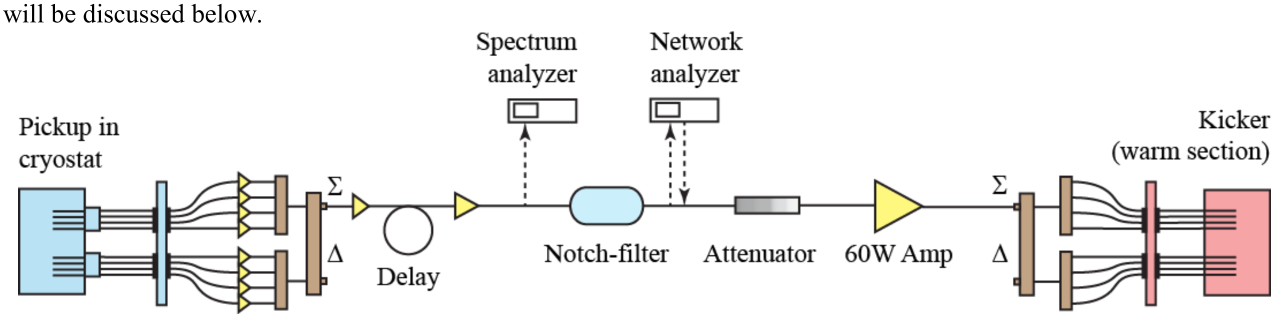


Figure 1: The scheme of stochastic cooling system in experiment.

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At first, longitudinal Schottky noise for deuterons at 2 GeV was measured. The bands were observed over the whole bandwidth, allowing the estimation of revolution frequency, momentum spread and form of beam distribution function. Figure 2 shows measured signals of a deuteron beam at 2.5 GHz.

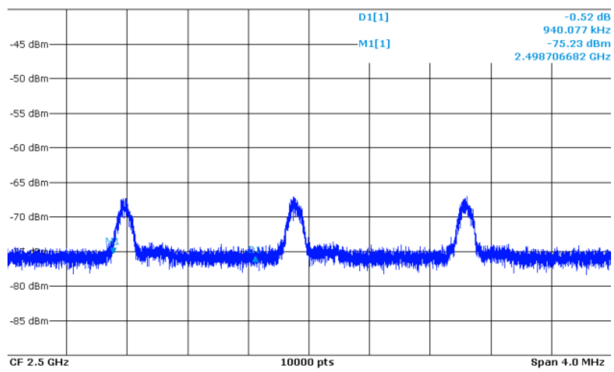


Figure 2: Longitudinal Schottky noise of coasting beam of deuterons ($10^9$ particles, 2 GeV/n), measured at 2.5 GHz.

The calculated momentum deviation at each harmonic corresponds to the nominal value of $10^{-3}$, as well as the revolution frequency of about 1.3 MHz.

The notch-filter was then inserted before the spectrum analyzer to make sure it works properly. Figure 3 demonstrates the work of the notch-filter, as it cancels the harmonics of revolution frequency, while its delay line is being adjusted.

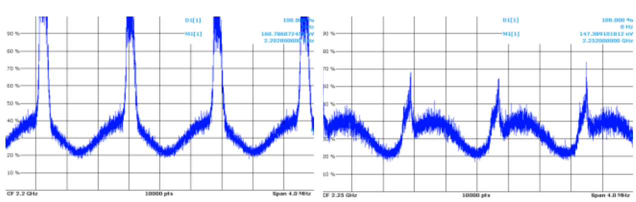

Figure 3: Longitudinal Schottky noise after notch-filter with imprecisely (left) and more precisely (right) adjusted delay line.

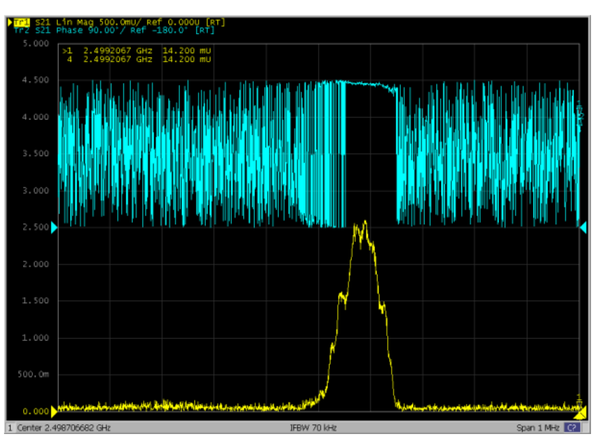


Figure 4: Amplitude (bottom) and phase (top) responses during BTF-measurements.

The next step was to measure the beam transfer function at different harmonics to adjust the system delay (open-loop measurements). The long branch of the notch-filter was broken to take into account the device delay only. One measurement at 2.5GHz is presented in Fig. 4.

The top curve represents the phase response, bottom the amplitude response. There were also observed double peaks, which nature was quite unclear during the experiment. While previous results guarantee the parts of the system from PU to main amplifier works properly, positioning and functionality of the kicker should be tested again.

## NEW SCHEME DESIGN

The stochastic cooling system at the Nuclotron is considered as a prototype for NICA, so further development of the system is necessary for NICA. This upgrade includes new schemes for signal handling at pick-up and kicker, a new optical delay line and an improved notch-filter. The scheme of combining the outputs of the pick-up is shown in Fig. 5.

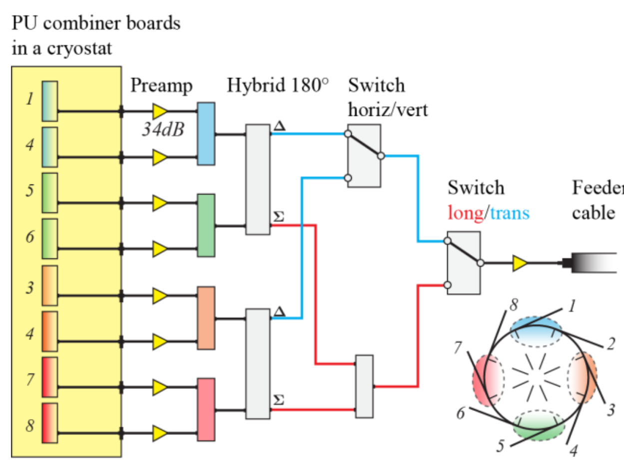


Figure 5: Scheme of combining pick-up outputs.

Eight outputs are first combined in four pairs in vertical and horizontal planes. Then utilizing two switches it is possible to get a vertical, horizontal or longitudinal signal. Kicker input signals are similarly handled except pre-amplifiers.

The delay lines and the notch filter were also revised. The delay lines for the system delay between pickup and kicker is now included in the optical notch filter, because fibers have negligibly small attenuations and dispersion. See the scheme of delay lines and notch-filter in Fig. 6. Both system and notch-filter delays include nanosecond-delay switches, ranging from 0.5 ns to 15.5 ns, and precise delay modules with 0-550 ps delay range and 0.01 ps accuracy. Using a variable delay allows adjusting the cooling system to specified beam energy in a fairly wide range. An attenuator in the short branch of the filter compensates the attenuation of the long branch, while an attenuator in the long branch is required to break the circuit for open-loop measurements.



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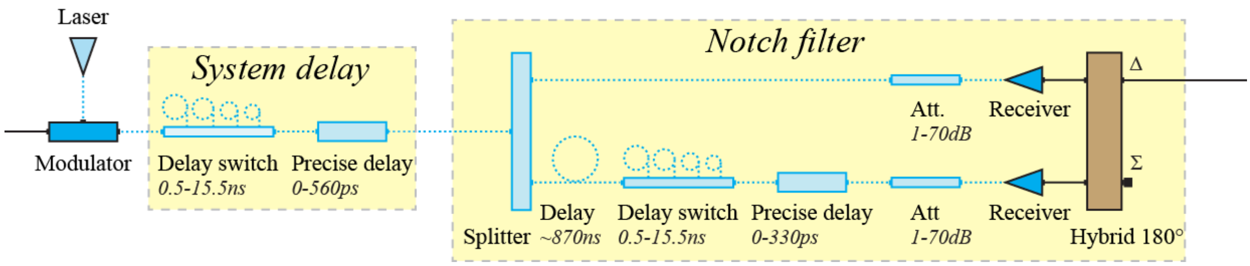


Figure 6: Optical delay line and notch-filter.

The new scheme also includes switches for open-loop measurements.

## PERSPECTIVES

The new scheme has been assembled in the test laboratory and measured component by component, and proved to be properly working. Closer to the run pick-up and kicker positioning will be checked again. Extensive simulations of beam evolution during cooling with the new scheme convince that in principle cooling effects can be seen in each cooling direction (longitudinal and transversal). For reference, the result of cooling for proton beam (intensity $10^9$, momentum deviation $10^{-3}$) with notch-filter scheme is shown in Fig. 7. Simulation for deuterons gives approximately the same result within 60s. During the following run it is planned to measure transverse and longitudinal Schottky noises, perform open-loop measurements and subsequently try different working modes of the new system.

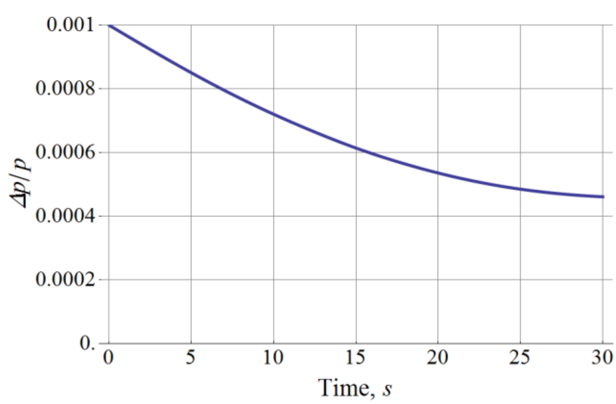


Figure 7: Simulation of momentum spread evolution during cooling. Protons at 3.5 GeV, $10^9$ particles, notch-filter method.

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