STOCHASTIC COOLING SYSTEM PROTOTYPE FOR NUCLOTRON

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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 to be operational in 2016 [1]. The luminosity in the colliding beams of Au^{79+} ions is expected to reach 10^{27} $cm^{-2}s^{-1}$. By met estimates it will mainly be determined by the intra-beam scattering effect. To suppress one, it was proposed to use the cooling of the beam. For the medium and high-energy heavy ions, such as NICA collider, stochastic cooling will be more efficient, then electron cooling, so this system will be used in the collider. In the coming years it's planned to build stochastic cooling system prototype at presently working accelerator Nuclotron to test different working modes at an early stage of NICA project. Main results of the development of stochastic cooling system at Nuclotron are presented.

INTRODUCTION

The Veksler and Baldin Laboratory of High Energy Physics (VB LHEP) of JINR is a pioneer in designing, constructing and commissioning the world first fast cycling synchrotron based on low-field iron dominated electromagnets with superconducting coils. This accelerator named Nuclotron was commissioned in 1993 [2]. Superconductive ring of 251,5 m in circumference is located in the tunnel with a cross-section of 2,5x3 m that was a part of the Synchrophasotron infrastructure. Since 1993 it was performed 41 beam runs at the accelerator. Presently the Nuclotron delivers ion beams for experiments on internal targets and for fixed target experiments using slow extraction system. Achieved energy of protons is 5.7 GeV, deuterons – 3.8 GeV/u and nucleons - 2.2 GeV/u.

The Nuclotron lattice is typical for a strong-focusing separated function synchrotron. It contains 8 superperiods. Each superperiod consists of three regular FODO cells. The fourth cell has not a dipole magnet. The regular cell includes F- and D-quadrupole magnets, four dipole magnets and two small drift spaces for the installation of correcting magnets, beam monitors, etc. In total the ring contains 96 dipole, 64 quadrupole, 32 correcting multipole SC-magnets. The betatron tunes are $Q_x \sim Q_y \approx 6.75$.

There are two straight sections on the direct opposite sides of the ring (Fig.1) where the pick-up and kicker can be installed.

The main argument to have operating stochastic cooling system prototype at Nuclotron - is to test different working modes of the machine. The first stage includes longitudinal cooling of the coasting deutron or light ion (lithium, carbon) beam using notch filter technique [3] for the cooling.

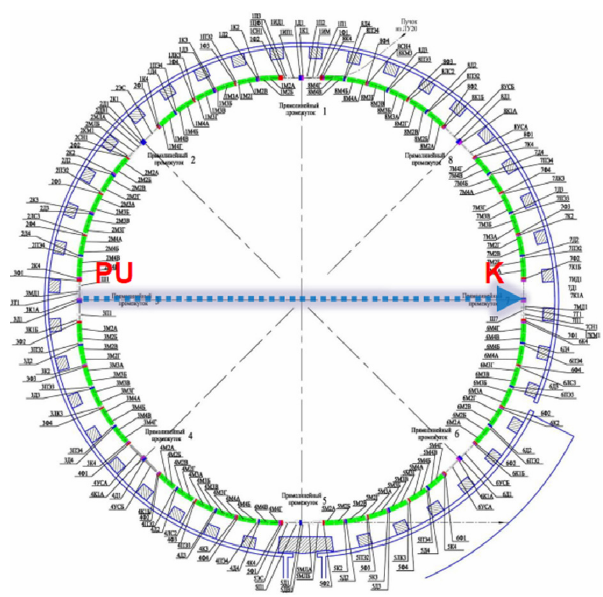

Figure 1. Nuclotron ring configuration.

Regular operation cycle duty of the machine is from 5 to 10 seconds, the flat-top time is around 80% of the duty cycle, therefore period available to get effect of the stochastic cooling process is limited to characteristic flat-top time. Main parameters of the accelerator summarized in Table 1.

Table 1. Nuclotron ring parameters

Circumference, m	251.5
Ions	up to A = 124
Energy, GeV/u	6
Rev.frequency, MHz	1.2
Vacuum, Torr	10^-10
Intensity	10^11(p)-10^9(C12)
dp/p	10^-3
Ring slippage factor	0.0322

SCHEME OF THE PROPOSED STOCHASTIC COOLING SYSTEM

The first step in realization of stochastic cooling experiment is longitudinal cooling of the coasting beam.

The dispersion value is too small in the section, where pick-up is placed, so Palmer method can not be implemented. Instead there is going to be installed a scheme with a notch filter. Octave band of 2-4 GHz was chosen for the system. The schematical picture of the assembly is shown on Fig.2

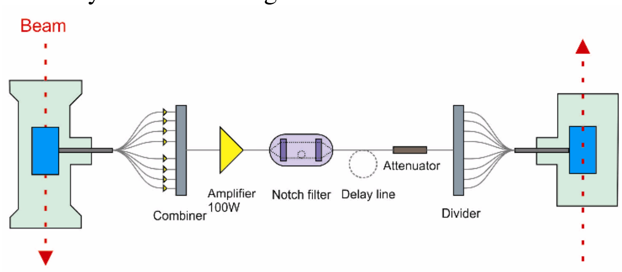

Figure 2. Scheme of the stochastic cooling system. Pick-up is on the left side, kicker is on the right.

The signal from the beam is measured with pick-up, installed in a specially designed vacuum chamber inside cryostat. Eight outputs for the beam signal from the pick-up are amplified with 40 dB preamplifiers and then combined together. The summarized signal is amplified after with 100W amplifier. Afterwards the signal follows to the notch filter which rejects the harmonics of revolution frequency and inverts phase of the signal. After is transported via variable delay line and variable phase-independent attenuator. Then the signal is divided by eight equal outputs, which are applied at the kicker for correction of the particle angle.

DESIGN AND CONSTRUCTION OF ELEMENTS

Installation includes the following components: pick-up and kicker electrodes assembly, pre-amplifier and amplifier, notch filter and delay line. For pick-up and kicker it is planned to use well-proved ring-slot couplers initially developed at COSY as a prototype for HESR ring [4]. Both pick-up and kicker have absolute similar design: assembly of 16 rings of 90mm aperture with 8 gold plated electrodes each (Fig 3).

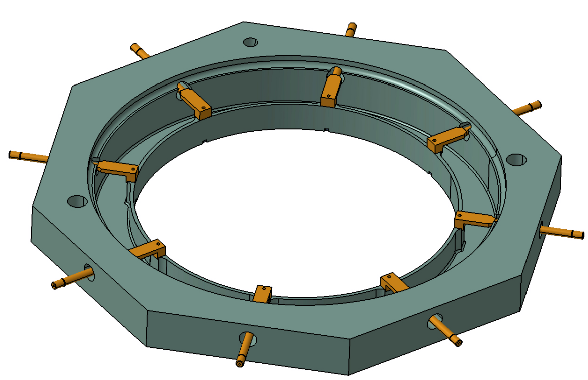

Figure 3. Design of the ring for slot-coupler

The basic principle of the beam signal formation at pick-up is the following. The total image current passes the surrounding uninterrupted gap formed by two adjacent rings. The round cell is somewhat like a classical iris loaded linac cell which is heavily loaded with the eight 50Ohm coaxial lines to obtain the octave bandwidth.

Each cell (ring) has eight shorted electrodes. The signal from different rings is gathered with the combiner boards, which have properly adjusted delays for different rings, so that the signal propagates in boards synchronously with the beam. Thus such a structure has correspondingly eight outputs, which are combined at dedicated board together afterwards for longitudinal signal.

The modular design of this structure allows an easy increase of the number of rings. Number of rings for kicker depends on the power required for delivery to the beam. Together with very good longitudinal coupling impedance it makes this device a good choice not only for Nuclotron, but for NICA as well.

Pick-up will be installed in the cold section of the ring (3^{rd} stright section) using special pick-up tank designed for installation In order to provide optimal operation of the pick-up (stability, signal sensitivity, noise reduction) it has to be placed in the cold section of the ring. Dedicated designed cryostat is under manufacturing now for installation of the pick-up structure at Nuclotron for operation at temperature close to 10K. This structure is an adapted version of pick-up tank presently using at COSY. The upper dome of the tank is made short as possible to prevent energy loss in cables.

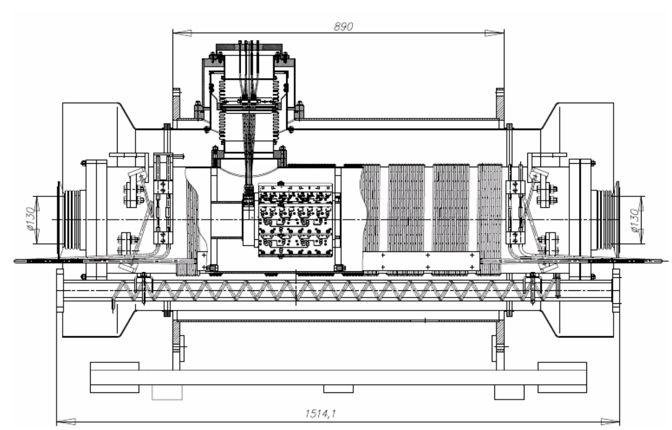

Figure 4. Pick-up assembly in Nuclotron cryostat.

Eight outputs from combiner boards will be delivered using special cables to 2 feedthrough flanges on the top of cryostat with 4 SMA connectors on each. Each output will be equipped with preamplifier.

Kicker slot-coupler assembly will be installed in the dedicated vacuum tank and located in the warm gap of Nuclotron (7^{th} straight section)

Optical notch filter

It is planned to construct notch filter with both optical legs, which gives advantages in gain value, regularity and uniformity of notches (Fig. 5).

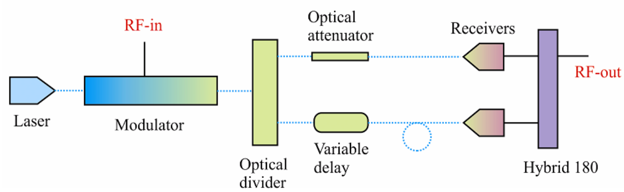

Figure 5. Notch filter layout.

Laser light is modulated by a RF signal from the longitudinal pick-up. After that the infrared signal is divided in two legs: in the 1st leg the attenuator is installed for power adjustments; in the 2nd leg the signal is delayed by a fibre optic coil and stretcher for precision adjustments. Afterwards RF signal is reconstructed by receivers and is combined by a hybrid. The basic scheme of such optical notch filter was initially proposed and tested in COSY [4].

COOLING PROCESS SIMULATIONS

Impedances of the pick-up and kicker are calculated through modeling the electro-magnetic field inside of the ring electrodes. Then the process of stochastic cooling is fully described with the Fokker-Planck equation[5, 6]:

$$\frac{\partial \Psi(E,t)}{\partial t} + \frac{\partial}{\partial E}(F(E)\Psi(E,t) - D(E,t)\frac{\partial \Psi(E,t)}{\partial E}) = 0$$

Where $\Psi(E,t) = \frac{dN}{dE}$ is a particle distribution function, and

$F(E) = f_0 \Delta E_c$

$D(E,t) = \frac{1}{2} f_0 \left\langle \Delta E_{ic}^2 \right\rangle$

$F(E)$ *and* $D(E,t)$ are coherent (cooling) and incoherent (heating) terms respectively. $\Delta E_c(E)$ - is the correction energy per turn, and ΔE_{ic}^2 - the incoherent noise effects for the particle.

Solving numerically this equation with introduced parameters of the real system, we can get the evolution of particle distribution function, evolution of momentum spread and value of power for the beam, required for cooling.

Simulations have been performed for different types of particles: protons and carbon ions C(6+). The results are presented at Figs. 6 and 7.

The results of the simulation give the following requirements for the system: in case of proton coasting beam, the power required for performing this experiment lays in 30-40W margins and gain is approximately 140dB. If the C(+12) beam will be used, the power requirements significantly decreases to 10W and 130dB gain correspondingly.

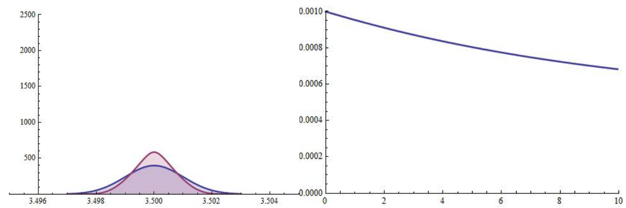

Figure 6. Expected evolution of particle distribution function and rms value of momentum spread for potons.

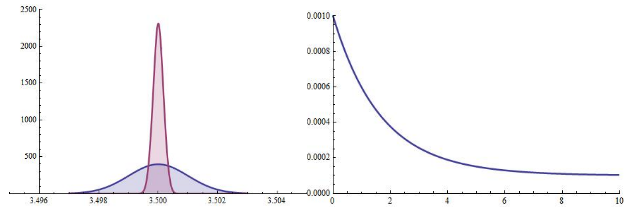

Figure 7. Expected evolution of particle distribution function and rms value of momentum spread for carbon ions (C6+)

CONCLUSIONS

Detailed design of stochastic cooling system prototype for Nuclotron have been performed: all components of the system were chosen and fixed. Design of vacuum and cryogenic vessels is completed. Within several months it is planned to start construction of the system in several stages. The first stage will include assembly of the dedicated test bench for producing and testing the notch filter. Second stage involves installing pick-up and kicker tanks with ring-slot couplers inside and measuring parameters of the system at warm test bench. The third stage includes installing the assembled stochastic cooling system and testing its work for longitudinal cooling.

ACKNOWLEDGMENTS

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