NEW COOLERS FOR ION ION COLLIDERS

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Abstract

For crucial contributions in the proof of principle of electron cooling, for leading contribution to the experimental and theoretical development of electron cooling, and for achievement of the planned parameters of coolers for facilities in laboratories around the world the 2016 *Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators* was awarded to Vasili Parkhomchuk. In this paper new future coolers for ion*ion collider will be discussed.

INTRODUCTION

The electron coolers are widely used for accumulation and cooling of heavy ions at storage rings. In 2016 the design and construction of the relativistic energy ion-ion collider NICA at Dubna were started. To obtain high luminosity at NICA it is extremely important to use powerful electron cooling of ions in collider regime for suppression of beam-beam effects at relatively low energy beams. In this report possible solution based on experience of high voltage cooler at COSY are discussed.

All modern collider will operate in bunch regime to obtain high luminosity. At beam collision point designed beta function in both transverse directions is very small and the bunch length should be less then value of beta function at collision point $\beta^\star$. As was first time demonstrated by Dag Reistad in cooling experiments at CELSIUS, at this condition very dangerous phenomena called "electron heating" can develop [1]. New generation of electron coolers try to use the hollow electron beam for control the transverse and longitudinal emittances as instruments against this phenomena [2].

COOLING BUNCHED BEAM

Usually for accumulation and cooling a regime without RF is used when ions beam are uniformly distributed along the orbit. In this case high frequency mode does not excite inside vacuum chamber. All modern colliders will operate in bunch regime to obtain high luminosity. For not too deep relativism the influence of longitudinal RF field from cavity and beam space charge fields determinate the longitudinal beam bunch profile.

At this conditions cooling and sinusoidal RF voltage lead to parabolic shape of ion bunch profile with sharp edges. Figure 1 shows the longitudinal shape of a proton bunch (1.6 GeV, 0.3 A electron beam at COSY) after acceleration and after electron cooling [3]. It is easy to see that after the main bunch the additional small bunches appeared because of high order oscillations at vacuum chamber. For a low energy cooling and the high intensity proton beam same transverse oscillations were detected Fig. 2.

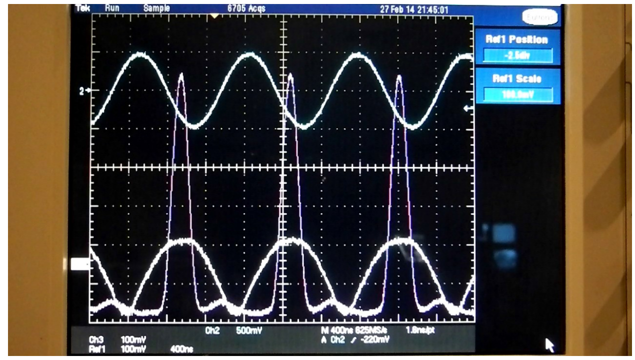

Figure 1: RF signal of proton beam profile before cooling and after cooling.

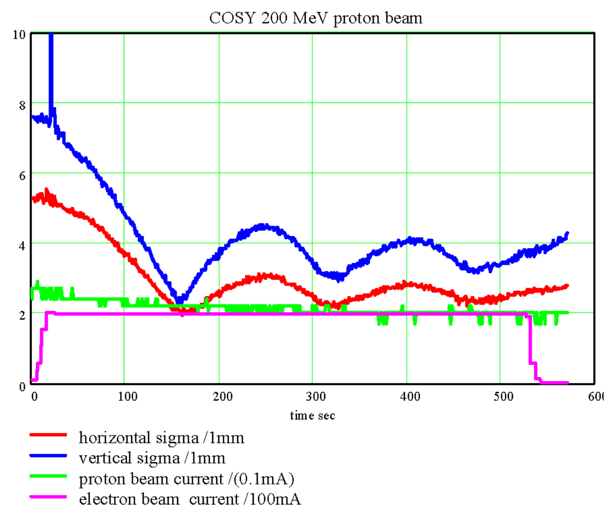

Figure 2: Periodical heating of proton beam on energy 200 MeV (COSY).

Decreasing of the proton beam intensity to less then 0.2 mA help to stop an unwanted oscillations "cooling-heating".

LEIR COOLER

The electron cooler for LEIR was the first of a new generation of coolers being commissioned for fast phase space cooling of ion beams in storage rings. It was a state of-the-art cooler incorporating all the recent developments in electron cooling technology (adiabatic expansion, electrostatic bend, variable density electron beam gun) and is designed to deliver up to 600 mA of electron current for the cooling and stacking of Pb^{54+} ions in the frame of the ions for LHC project (2006).

Figure 3 shows the horizontal beam size measured by the Ionization Profile Monitor during the whole LEIR cycle. As the cooling progresses the beam emittance is reduced by more than a factor of 30 at time 0.2 s. After acceleration to the extraction energy the measured emittance was typically 0.2 mm, well within the 0.7 mm needed for the LHC beam.

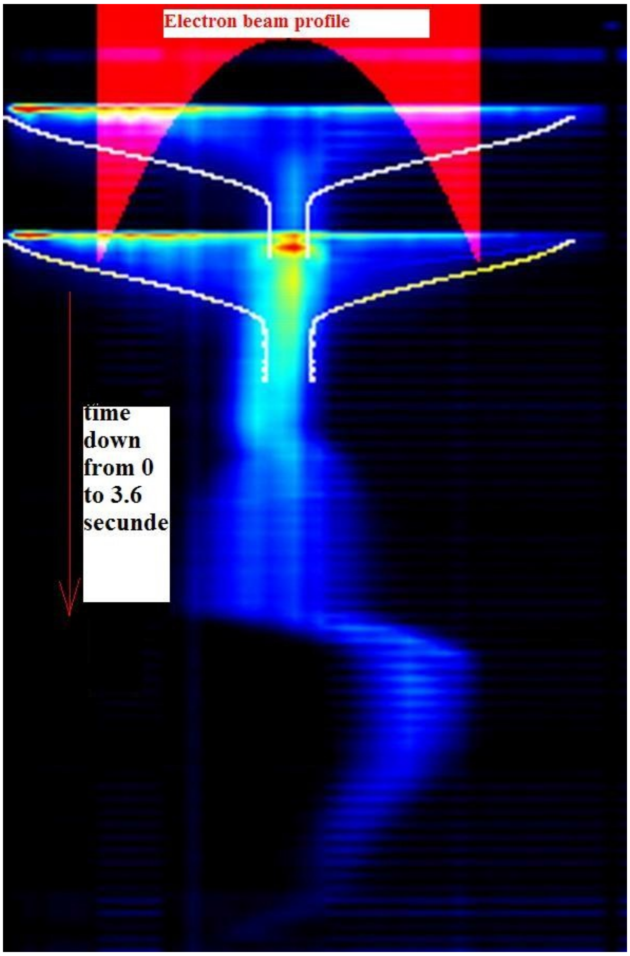

Figure 3: Two shut injection Pb^{54+} beam, cooling and acceleration at 3.6 s cycle LEAR running.

The electron beam shape used for cooling is shown on Fig. 3 by red colour with minimum at centre of beam. This profile increases of the cooling rate for high amplitudes of betatron oscillations and decreases cooling rate at the core of ion beam for suppression of overcooling which leads to development of coherent instability. For control the electron beam profile special electrode at the electron gun is used.

Figure 4 demonstrates design of toroidal plates used for electrostatic bending of electron beam. It leads to the same trajectory of electrons reflected from collector. At this case reflected electrons return again at collector and are adsorbed inside well outgases collector. Loss current can be decreased from 1 mA to 1 μA that help to obtain extremely low vacuum pressure.

COSY COOLER

At COSY cooler the electron gun control electrode consists of 4 sectors with individual potentials at each sector (Fig. 5). As a results the electron beam profile consist from 4 individual beams. It gives chance to measure not only position of electron beam but the shape of the beam along trajectory. 12 pickup stations are installed along vacuum chamber to measure centre of electron beam and its 4 fractions by modulation individual sectors at electron gun separately. Using this technique it is possible to measure rotation of electron beam along trajectory and measure ion compensation of electron beam.

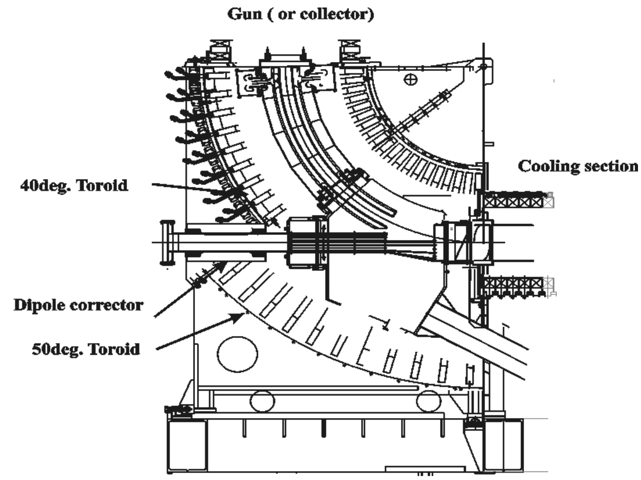

Figure 4: Electrostatic bending plates at toroidal field.

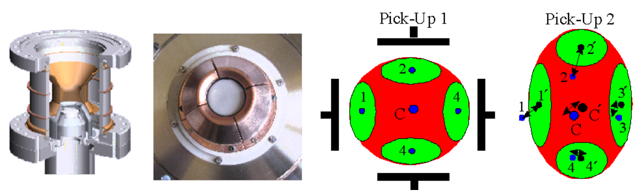

Figure 5: The COSY electron beam design with 4 individual beams.

Using small variation of longitudinal field in cooling section it is possible to detect Larmor spiralling motion of beam as show Fig. 6.

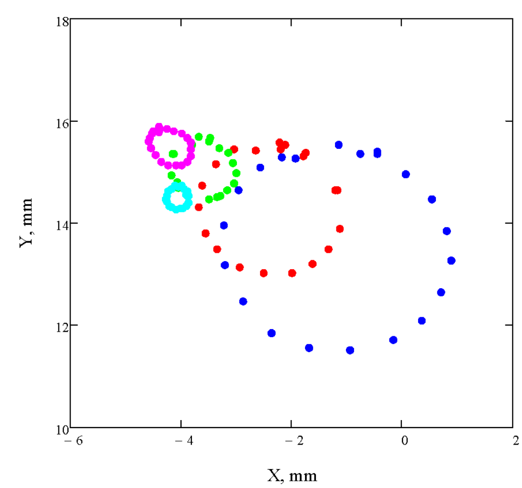

Figure 6: The changing of x, y position of electron beam centre at process of variation of the current at cooling solenoid 250–270 A for different dipole kicks of electron beam.

It easy to see that two x, y short kicker magnets outside cooling section can compensate Larmor spiralling. After optimisation of beam centre spiralling it is possible to see small amplitude rotation at 4 beams outside centre Fig. 7. To continue decreasing of transverse rotation in electron beam and to improve cooling rate it is necessary to use quadruple kickers and short magnet lenses along beam trajectory. The proton beam on energy 2.3 GeV was cooled transverse and longitudinally at time near 100 s. At this experiment was tested cooling with using at the same time running stochastic and electron cooling [4].

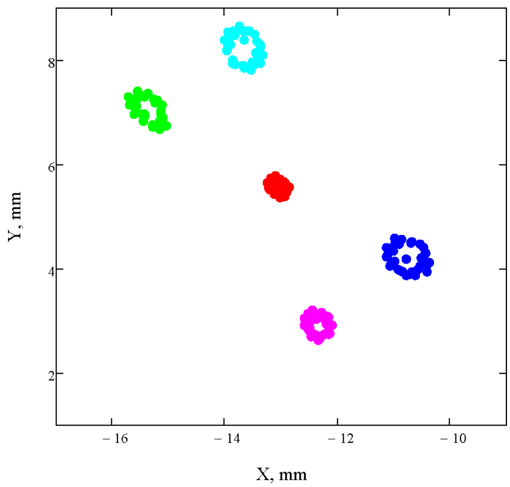

Figure 7: Motion of electron beam centre and 4 fractions of beam out of centre.

NICA COOLERS

At 2016 the cooler for NICA collider was commissioned with electron beam at BINP (Fig. 8). The design of the cooler for NICA booster is very close to LIER design. But new electron gun with 4 sector control electrode is used and 4 beam position monitors are installed along electron beam. This 4 BPM were very useful for optimization of passing of electron beam along orbit. New system of vacuum pumping achieved 2·10-11 mbar pressure with electron beam current 0.7A. At the end of 2016 cooler will be shipped to Dubna for assembling with NICA booster.

For the NICA collider RND work on 2.5 MeV cooler is started Fig. 9. The cooler is intended for suppression of intra beam scattering in bunched ions beam.

ACKNOWLEDGMENT

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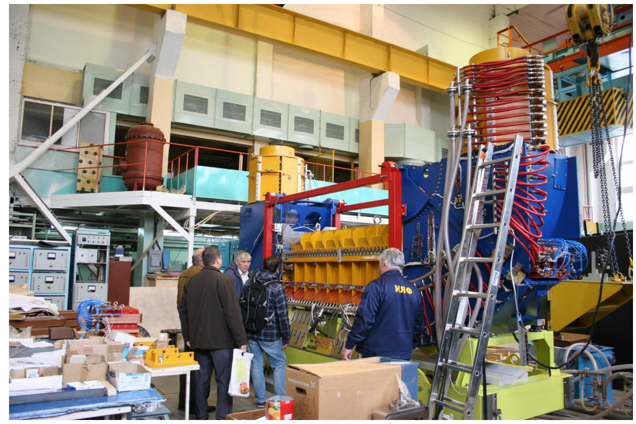

Figure 8: Cooler for the the NICA booster.

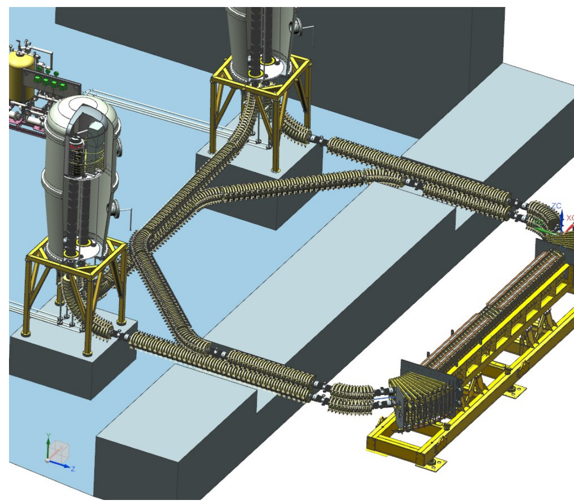

Figure 9: The preliminary design of 2.5 MeV coolers for NICA collider.

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