RECENT EXPERIMENTS WITH HIGH ENERGY ELECTRON COOLER IN COSY

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Abstract

The 2 MeV electron cooling system for COSY-Julich started operation in 2013 years. The cooling process was observed in the wide energy range of the electron beam from 100 keV to 1.256 MeV. Vertical, horizontal and longitudinal cooling was obtained at bunched and continuous proton beam. This report deals with electron cooling experiments at COSY with proton beam at energy 1.66 and 2.3 GeV. The proton beam was cooled at different regimes: RF on and off, barrier bucket RF, and cluster target on and off.

SETUP DESCRIPTION

The COSY cooler (see Table 1) may be used in experiments with polarized and unpolarized protons and deutrons with energies of up to 2880 MeV/u on the internal target or with extraction of the beam to the external target. In experiments with the internal target, the possibility of cooling the beam (i.e., of decreasing the spread of the particle momenta to suppress "warming effects") is of great importance. Today, three cooling systems are already used in the COSY. Electron cooling to low electron energies (about 200 MeV) allows researchers to accumulate charged particles and raise the phase density of the beam prior to subsequent experiments. Stochastic cooling [1, 2] prevents the quality degradation of a beam interacting with a target at typical experimental energies. Unfortunately, stochastic cooling suffers from natural limitations, which hinder the operation of the synchrotron at a high intensity of the cooled beam and a small spread of the cooled particle momenta. Electron cooling at experimental energies can effectively prevent small angle scattering and ionization losses. Both factors are most probable when the energy of particles interacting with a material is high. When combined with stochastic cooling, electron cooling is expected to greatly enhance the luminosity in experiments with the internal target.

The schematic design of the high-voltage cooler is shown in Fig. 1. The design of the cooler and its main parameters are described in [3-5]. The electron beam is accelerated by an electrostatic generator that consists of 33 individual sections connected in series. Each section has two high-voltage power supplies with maximum voltage 30 kV and current 1 mA. The electron beam is generated in electron gun immersed into the longitudinal magnetic field. After that the electron beam is accelerated, moves in the transport line to the cooling section where it interacts with protons and deuterons of COSY storage ring. After interaction the electron beam returns to electrostatic generator where it is decelerated and absorbed in the collector.

Table 1: COSY Regime Parameters

Parametere	Value
Gamma transition	2.26/2.287
Proton numbers	10^8-10^9
Kinetic energy	1.66/2.3 GeV
Vacuum	10^{-9}-10^{-10} mbar
Qx	3.59-3.65
Qy	3.675-3.64
Slip-factor	-0.066/-0.1
Perimeter	183.5 m
Revolution frequency	1.524/1.564MHz
Electron energy	909/1265 kV
Electron current	0.5-0.8 A
Radius of electron beam in the cooling section	0.5 cm

EXPERIMENTS SETUP

The diagnostic of the proton beam was based on IPM (ionization profile monitor) and pickup of the stochastic cooling system. The proton current is measured by DCCT.

The transverse profiles of the beam were determined in real time with a profile monitor that measures the profiles of ions produced by electron beam ionization of residual gas. The momentum distribution was measured with pickup of the stochastic cooling system. The harmonic for Schotky noise detection was 1250.

The main parameters of COSY regime are listed in Table 1 for the regime with proton energy 1.66 and 2.3 GeV.

EXPERIMENTS WITH ENERGY 1.257 MEV

The most experiments in run 2014-2015 were carried out with electron energy 908 keV. The next step to high-voltage was done to energy 1.257 MeV. Before the cooling process the training of the high-voltage column was

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done (see Fig. 2). During this process leakage current through SF_6 gas decreased from 20 uA to 9 uA. The black lines show the level of the leakage currents in the different moment of the time.

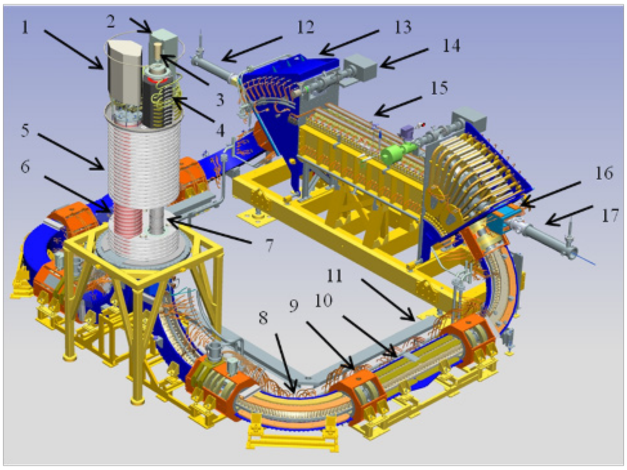

Figure 1: 3D design of 2 MeV COSY cooler. Collector PS is 1, gun and collector PS is 2, ion pumps are 3,14, collector is 4, HV section is 5, cascade transformer is 6, acceleration tube is 7, bend 90 is 8, straight section is 9-10, cable path is 11, proton beam in/out are 12,17, toroid 45 is 13, cooling section is 15.

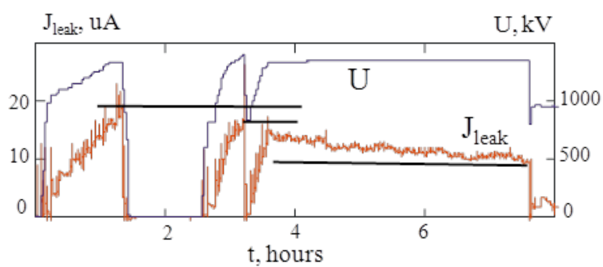

Figure 2: Training procedure of high voltage for 1.257 MeV.

After training the first electron beam with current 0.5 A was obtained. The electron energy was calculated initially from storage ring parameters as 1256.6 kV. The first the obvious shift in Schottky spectrum was observed induced by the electron cooling force. The spectrogram of this process from Schottky pickup is shown in Fig. 3 (left). The mismatch between the electron and ion velocities is large but the cooling force enough for changing revolution frequency of the proton beam. The proper value of the electron beam was found at 1259.5 kV by experimental way (see Fig.3, right). The duration of both spectrograms is about 570 s .

The Parkhomchuk' equation [6] can be rewritten in the form

$$\frac{\delta p_{//}}{p_0} = \gamma^2 \beta L_N \left(\frac{m_e c^2}{\delta E_e} \right)^2 r_e r_p n_e \tau c f_0 \Delta T$$

for large deviation between particle velocities. Here r_e, r_p are the classical radiuses of proton and electron, f_0 is the revolution frequency, ΔT is duration of the cooling, $m_e c^2$ is the rest energy of electron, δE_e is the difference between electron energy and its optimum value for cooling, $n_e = 4 \cdot 10^7$ cm^{-3} is the electron density in co-moving system. The Coulomb logarithm is

$$L_N = \ln\left(1 + \frac{\delta V \cdot \tau}{\rho_L}\right),$$

where $\delta V \cdot \tau = \delta E_e \cdot \tau / (\gamma \beta m_e c)$ is maximum impact factor, ρ_L is Larmour radius that can be estimated for first experiments as $\rho_L = 100$ μm, $\tau = l_{cool} / (\gamma \beta c)$ is flight of the cooling section with length l_{cool} .The cooling rate from this estimation gives changing the proton momentum about $2.1 \cdot 10^{-4}$ during 300 s that is close to observed effect in Fig. 3. In the case of the matched velocity the cooling process is faster (see Fig. 3, right).

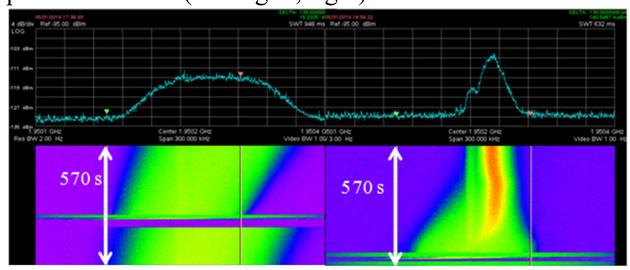

Figure 3: Spectrogram of the cooling process with strong (left) and small (right) difference between the electron and ion velocities. The electron energy is 1256.6 kV, electron current is 0.5 A. The span of the longitudinal momentum is $\delta p/p = 1.5 \cdot 10^{-3}$.

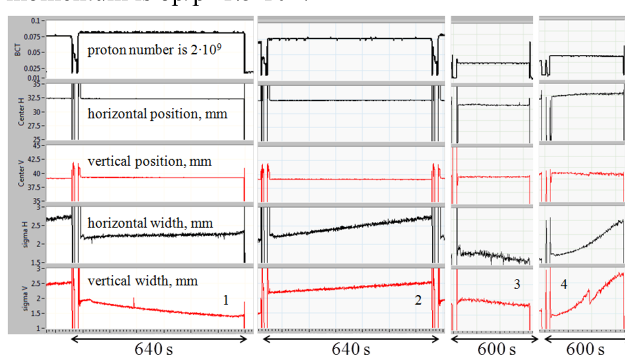

Figure 4: Changing transverse size during cooling experiments. Curve 1 is cooling at energy 909 kV, curve 2 is reference cycle without cooling, curve 3 is cooling at energy 1259 keV, curve 4 is growth of the transverse size at changing working point (tune) despite of electron cooling action.

The transverse cooling in the run 2016 is demonstrated in Figure 4. The results became more inconsistent than the transverse cooling obtained in runs 2014/2015. The possible reason is dependence of the cooling process from the working point of the storage ring. Figure 4 shows the transverse size of the proton beam with e-cool and without it. The curve 2 shows the transverse dynamic of the proton beam without cooling process. One see growth of the beam emittance that nature wasn't clear. The curve 4 shows the worse situation with emittance growth at changing working point from local optimum at $\Delta Qx/\Delta Qy$ = 0.02/-0.01. The similar effects were observed in electron cooling experiments at injection energy [7]. The best

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electron cooling at energy 909 kV was obtained in the run 2015 (see Fig. 5). The cooling time about 100 s was obtained.

The electron cooling at presence of target and barrier bucket RF was investigated at energy 909 kV. Figure 6 shows that the barrier bucket RF and electron cooling suppress the longitudinal action of the target. The presence of target did not change the longitudinal momentum spread and the longitudinal shape of the proton bunches. The barrier bucket itself (see Fig. 7) wasn't able to suppress the target ionization loss. The particle escapes from the bucket.

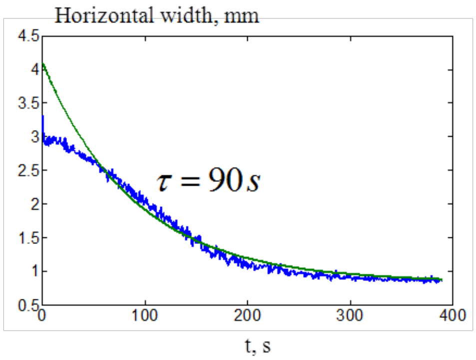

Figure 5: Horizontal cooling at electron energy Ee=909 kV. Number of the proton is $3 \cdot 10^8$, the electron current is 800 mA.

The strength of the electron cooling enough to suppress of the ionization loss and straggling without help of the barrier bucket. Figure 8 shows the experiment with cooling of the proton beam with target without barrier bucket. One can see that the electron cooling practically suppressed longitudinal and transverse growth induced by target but the more precise tuning storage ring and e-cooler is necessary.

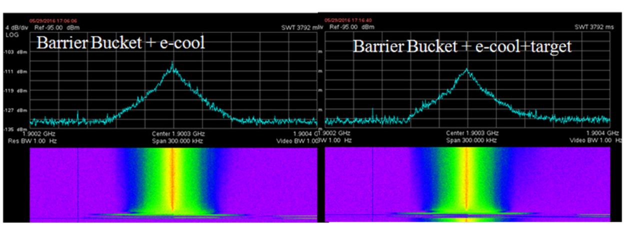

Figure 6: Spectrogram of Schotkky signal at the combine action barrier bucket RF and electron cooling (left picture) and barrier bucket, electron cooling and target (right picture). The electron energy 909 kV, electron current is 570 mA, the proton number is $2 \cdot 10^9$, $U_{RF} \approx 200$ V. The duration of the spectrum is about 300 s.

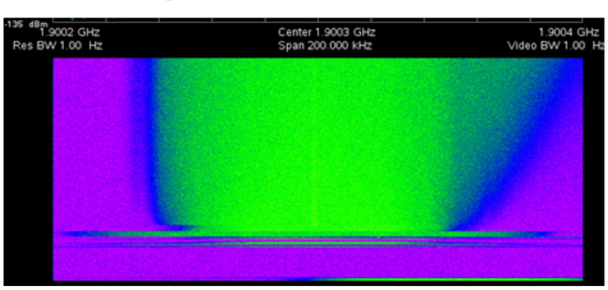

Figure 7: Spectrogram of Schottky signal at the simultaneously action barrier bucket and target. The spectrum duration is about 550 s.

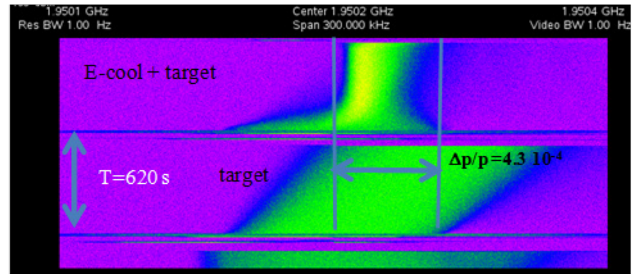

Figure 8: Spectrogram of the cooling process with electron cooling and target. The electron energy 1259.6 keV, the electron current is 500 mA, target with density is $n_a = 2 \cdot 10^{14}$ cm^{-2}.

CONCLUSION

The first successful experiment was carried out in COSY with electron energy 1257 keV. The experimental results show usefulness the electron cooling device with strong longitudinal magnetic field for improving quality of the proton beam. The electron cooling may be useful in combination with barrier bucket and usual RF. The electron cooling suppresses the action of the target with density $n_a = 2 \cdot 10^{14}$ cm^{-2}. The role of the working point and optics of the storage ring at cooling process should be investigated more carefully

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