COMMISSIONING 2 MEV COOLER IN COSY AND NOVOSIBIRSK

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Abstract

The 2 MeV electron cooling system for COSY-Julich was proposed to further boost the luminosity in presence of strong heating effects of high-density internal targets. The 2 MeV cooler is also well suited in the start up phase of the High Energy Storage Ring (HESR) at FAIR in Darmstadt. It can be used for beam cooling at injection energy and for testing new features of the high energy electron cooler for HESR. The COSY cooler is designed on the classic scheme of low energy coolers like cooler CSRm, CSRe, LEIR that was produced in BINP before. The electron beam is transported inside the longitudinal magnetic field along whole trajectory from an electron gun to a collector. The 2 MeV electron cooler was installed in the COSY ring in the spring 2013. Electron beam commissioning and first studies using proton and deuteron beams were carried out. Electron cooling of proton beam up to 1662 MeV kinetic energy was demonstrated. Maximum electron beam energy achieved so far amounted to 1.25 MeV. Voltage up to 1.4 MV was demonstrated. The cooler was operated with electron current up to 0.5 A.

SETUP DESCRIPTION

Electron cooling is very useful technique for obtaining high-quality ion beams with high-intensity and low momentum spread [1]. In this method, the phase-space density of an ion beam is increased with a Coulomb interaction of a “hot” ion beam with a “cold” electron beam. Therefore, the ion beam repeatedly transfers its thermal energy to the electron beam moving with the same velocity.

There are many experiments and theoretical calculation that shows the useful of the magnetized cooling. These experiments and calculation was done in the different scientific centres in the world. The 2 MeV cooler at COSY is the first device utilizing the idea of magnetized cooling in this energy range, being an important step towards relativistic electron cooling required for the HESR at FAIR. Furthermore, it has been shown, that the 2 MeV cooler, if installed in the HESR, can be used without changes for the heavy ion operation modes [2,3].

First ideas was formulated in 2003 and a first report was published in 2005 [4].The construction of the 2 MeV electron cooler for COSY began at the Budker Institute of Nuclear Physics (BINP) in 2009 and ended 2012. In spring 2013 the cooler was installed in the COSY ring. First beam cooling results were obtained in October 2013 by the joint BINP-COSY team. Further beam cooling experiments followed during a two-week period of dedicated beam time beginning of 2014. At that time a first attempt to use electron and stochastic cooling in the same machine cycle was made. Furthermore, electron cooling of proton/deuteron beam into a barrier bucket was demonstrated. The design of the cooler and its main parameters are described in [5].

The schematic design of the setup is shown in Fig.1. 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 will interact with protons of COSY storage ring. After interaction the electron beam returns to electrostatic generator where it is decelerated and absorbed in the collector.

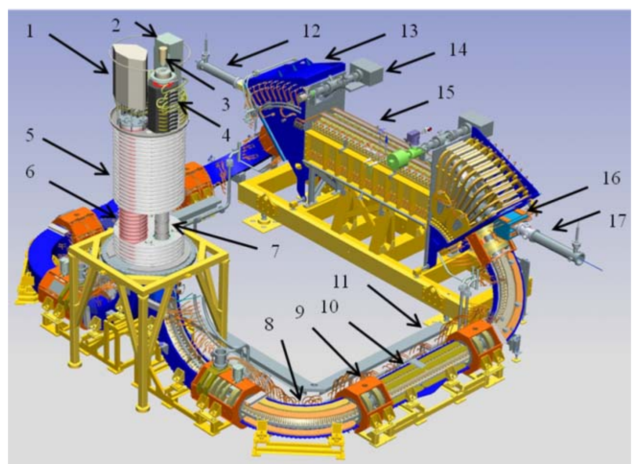

Figure 1: 3D design of 2 MeV COSY cooler. Collector PS is 1, SGF system is 2, ion pump of collector is 3, collector with magnetic system is 4, HV section is 5, cascade transformer is 6, acceleration tube is 7, bend 90 degrees is 8, straight section is 9, line section is 10, cable path is 11, input of the proton beam is 12, toroid 45 is 13, vacuum pump is 14, cooling section is 15, ion dipole is 16, output of the ion beam is 17.

The optics of 2 MeV cooler for COSY is designed close to the classical low-energy coolers. The motion of the electron beam is magnetized (or close to magnetized conditions) along whole trajectory from a gun to a collector. This decision is stimulated by requirement to operate in the wide energy range from 25 keV to 2 MeV. So, the longitudinal field is higher then transverse component of the magnetic fields. The bend magnets and linear magnets of the cooler are separated by a section

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with large coils for the location of the BPMs, pumps and a comfort of the setup assembling. The length of the linear magnets is defined by the necessity to locate the electrostatic generator outside the shield area of the storage ring.

The vacuum chamber is pumped down by ion and titanium sublimation pumps. The typical diameter of the vacuum chamber is 100 mm and the aperture in the transport channel and cooling section is close to this value. The diameter of the accelerating tube is 60 mm.

HIGH-VOLTAGE AND RECUPERATION STABILITY

The final of the electron beam commissioning in Novosibirsk was stay during 6 days and nights at the energy 1 MeV and currents 200 mA. Figure 2 shows the example of the long-term training regime. Sometimes the recuperation breakdown occurs often and some time rarely. It seems that this behaviour can be improved by a training procedure. The physical nature of breakdowns isn't clear because any precursors weren't observed before breakdown. The spontaneous recuperation breakdowns were observed also at low energy (30 kV for example). Today the main hypothesis concerned with the fast changing of the vacuum condition in the accelerator tubes. It can be induced by some dust particle evaporation or the accumulation of the secondary ions. The ions can be trapped in the potential well formed by the electron beam. After reaching a threshold value the accumulated ions fast escape from the trap region to the vacuum chamber and accelerating tube which has negative potential respect to the ground. The pumping of the secondary ions with special device slightly improves the situation with breakdowns but it doesn't solve this problem completely. The typical vacuum value is a few 10^{-8} mbar.

More accurate vacuum assembling and careful vacuum baking procedure make it possible to obtain the vacuum 10^{-9}-10^{-10} in whole electron cooler in Juelich. The situation with spontaneous breakdown was improved but the detail investigation wasn't done. Figure 3 shows the example of the operation with high-voltage in COSY.

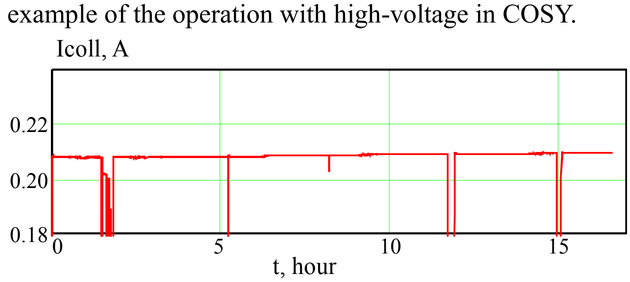

Figure 2: Electron current versus time. Fragment of training regime with electron beam in BINP.

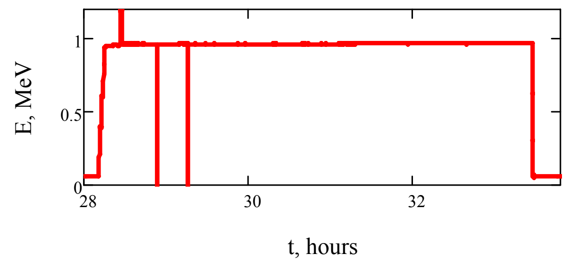

Figure 3: Example of the operation with high-voltage in COSY.

FIRST COOLING EXPERIMENTS

The first electron cooling experiments was done with electron energy 109 kV and the proton energy 200 MeV. The longitudinal magnetic field in the cooling section is 530 G.. The choice of such energy is avoidance of the problem with electron beam tracing. Such electron energy is small enough for the strong adiabatic motion of the electron along its trajectory, but the proton beam life is higher as compared with the injection energy. Because the observing of the electron cooling effects is easy at small value of the electron friction force until the situation when all parameters are acquiring the optimum values.

Figure 4 shows the parameters of the proton beam versus time. One can see that the sizes of the proton beam decrease from 5÷7 mm to 1 mm. The losses of the proton beam are small enough.

Increasing of proton beam intensity leads to growth of the proton beam losses. At initial proton current 3.7 mA the intensity of the proton beam decreases in factor 3 during cooling procedure.

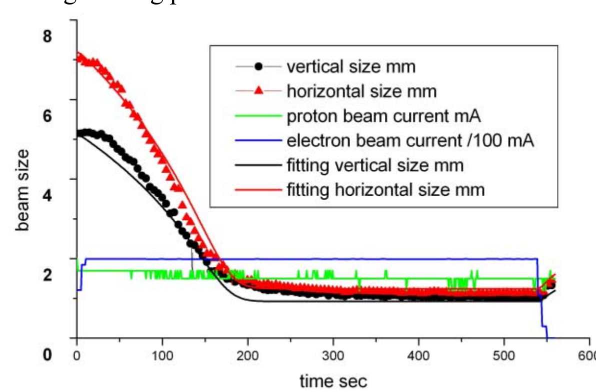

Figure 4: Parameters of the proton beam versus time during the electron cooling process

JOINT ACTION OF ELECTRON AND STOCHASTIC COOLING

The storage ring COSY is equipped by the system of the stochastic cooling. In time of the electron cooling experiments the stochastic system was tuned on the energy corresponding to the energy of the electron beam 908 kV and it was operated in the vertical direction only. The experiment with joint action of the different cooling

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systems was done at this energy. Figure 5 shows the sizes of the proton beam at the different conditions.

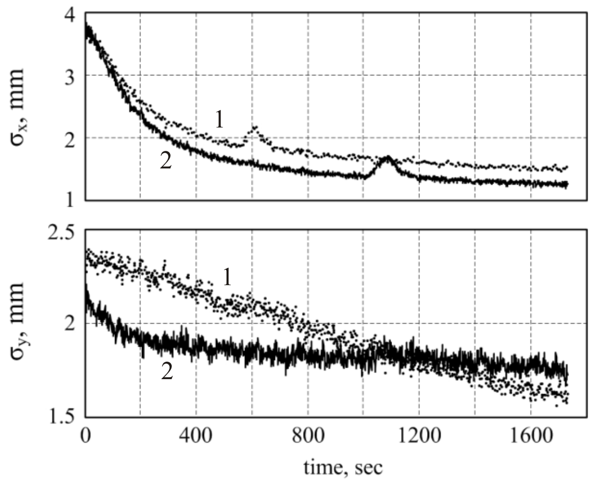

Figure 5: Sizes of the proton beam versus time at the different condition of the experiments. The action of electron beam only is 1, the joint action of the electron and stochastic cooling in vertical direction is 2.

One can see that the joint action of the cooling systems makes it possible more deep shrinking of the proton beam in the horizontal direction. The dynamics of the vertical size is different essentially. The vertical size of the proton beam decreases very fast in initial time but the action of the electron cooling system only enables to receive smallest size of the proton beam in compare with joint action of the cooling systems. This effect may be explained by the excitation of a coherent instability. The signal from the Schotky pick-ups showed strong oscillation when the proton beam was cooled significantly. The vertical size increases in this moment, the horizontal size remains same. The electron cooling force is enough for preserving of the horizontal size but the excitation is absent.

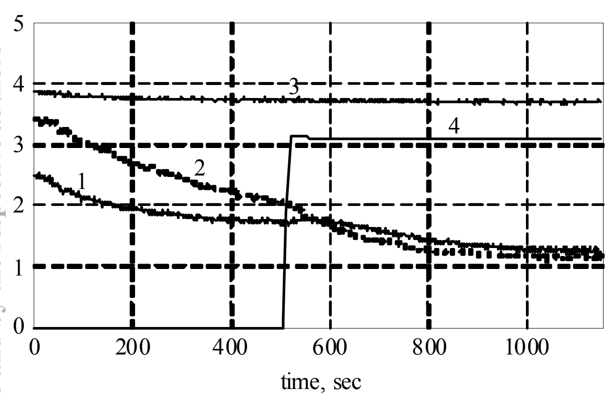

Figure 6: Parameters of the proton beam versus time. The vertical size is 1, the horizontal size is 2, the proton current is 3 (in unit 100 uA), the electron current is 4 (in unit 100 mA).

Figure 6 shows the dynamics of the proton beam in machine cycle with action of both cooling systems. In first moment the stochastic cooling was used only. In the middle of cycle the electron cooling was added. The rate of the cooling in the transverse direction became higher.

The experiments with joint action of the electron and stochastic cooling is very important because the stochastic cooling is very effective at large amplitude of the betatron oscillation, but the electron cooling is effective at small betatron amplitudes.

SUMMARY

The key problems of the electron cooler 2 MeV (modular approach of the accelerator column, the cascade transformer, the compass base probe located in the vacuum chamber, the design of the electron gun with 4-sectors control electrode) is experimentally verified during commissioning in Novosibirsk.

The first successful experiment was carried out in COSY with 2 MeV electron cooling device. The large range of the cooling energy for operation makes it possible to cool the proton beam with energy from 200 MeV to 1.66 GeV. The experimental results show usefulness the electron cooling device with strong longitudinal magnetic field for improving quality of the proton beam.

AKNOWLEGMENTS

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