ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI075

COSY 2 MEV COOLER: DESIGN, DIAGNOSTIC AND COMMISSIONING

V. B. Reva, N.I. Alinovskiy, T. V. Bedareva, E.A. Bekhtenev, O.V. Belikov, V.N. Bocharov, V.V. Borodich, M.I. Bryzgunov, A.V. Bubley, V. Chekavinskiy, V. Cheskidov, B. Dovzhenko, A. Erokhin, M. Fedotov, A.D. Goncharov, K. Gorchakov, V. K. Gosteev, I. Gusev, A. Ivanov, G. Karpov, Yu. Koisin, M. Kondaurov, V. Kozak, A. Lisitsyn, I. Lopatkin, V. Mamkin, A.S. Medvedko, V.M. Panasyuk, V.V. Parkhomchuk, I. Poletaev, V. Polukhin, A. Protopopov, D. Pureskin, A. Putmakov, P. A. Selivanov, E. Semenov, D. Senkov, D.N. Skorobogatov, N.P. Zapiatkin , BINP, Novosibirsk, Russia
V. Kamerdzhiev, Lijun Mao, FZJ, COSY, Juelich, Germany
J. Dietrich, TU Dortmund University

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. This optic scheme is stimulated by the wide range of the working energies 0.025-2 MeV. The electrostatic accelerator consists of 33 individual unify section. Each section contains two HV power supply and power supply of the magnetic coils. The electrical power to each section is provided by a cascade transformer. This report describes the cooler design, diagnostics, control system and the result of the commissioning in BINP and FZJ at the different energies.

INTRODUCTION

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. As it is generally known, the electron cooling estimation with the simple plasma ion-electron model of the temperature relaxation and the first experimental results confirmed this fact. After modernization of the experimental setup the cooling time was decreased significantly. The homogeneity of the magnetic-field in the cooling section was improved to 10^{-4} and the stability of the electron energy was improved to 10^{-5}. The theoretical and experimental investigation were shown that the reason is difference in the collision dynamics of electrons and ion at the presence of the strong longitudinal magnetic field that distinguish it from the usual relaxation of a two-component plasma [2]. The ion interacts with not single electron but with a blur Larmour circle.

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 MOSOL experiments [3] and VORPAL calculations [5] shows the slightly growth of the friction force with growth of the value of the longitudinal magnetic field. The article [6] shows the decreasing influence of the transverse velocity to the cooling rate. The transverse velocity was induced by a kick with the special electrostatic plates. The kick effect was observed in the recombination rate but the measured cooling rate was not changed significantly. The work [7] deals with the investigation of the cooling force in S-LSR device. The comparison of the experimental facts with the different theory model was done and the rate calculated according Parkhomchuk’s equation [4] was closest to the experimental data. The magnetization rate of the cooling force had the maximum value.

The basic idea of this cooler is to use high magnetic field along all orbit of the electron beam from the electron gun to the electron collector. At this case we have chance to have high enough the electron beam density at cooling section with low effective temperature. The 2 MeV electron cooler for COSY has the highest energy from all coolers that was made with idea of magnetized cooling and transport of the electron beam. The potential of the classic way isn’t unexhausted and may be used for high energy electron cooler for HESR [8].

DESIGN DESCRIPTION

The schematic design of the electron cooler is shown in Fig. 1. The electron beam is generated by an electron gun and accelerated by an electrostatic generator that consists of 33 individual sections connected in series. The electron beam is generated in electron gun immersed into the longitudinal magnetic field. After acceleration the electron beam moves in the transport line to the cooling section where it interacts with protons of COSY storage ring. After interaction the electron beam returns to electrostatic generator where it is decelerated and absorbed in the collector.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI075

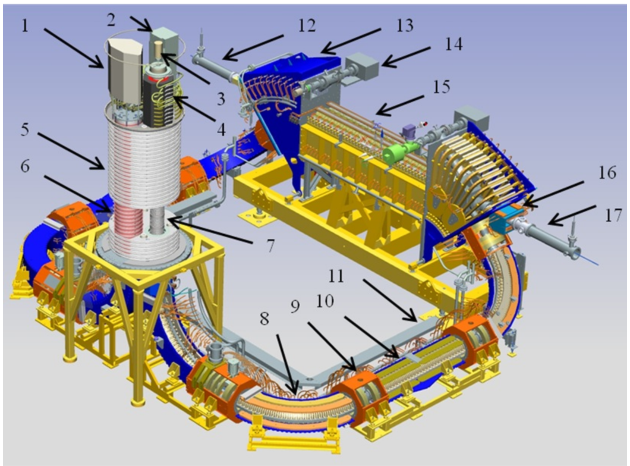

Figure 1: 3D design of 2 MeV COSY cooler. Collector PS is 1, SGF system is 2, ion pump of collector is 3, collector with magnetic system is 4, HV section is 5, cascade transformer is 6, acceleration tube is 7, bend 90 degrees is 8, straight section is 9, line section is 10, cable path is 11, input of 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 electron gun and the collector are located in high-voltage terminal (HVT) on the top of the accelerating column. In addition the HVT contains electronics blocks providing control for the element of the electron gun (filament, four control grid electrodes, anode, potential of HVT respects to accelerating tubes), collector (powerful collector rectifier, Wien filter electrodes, suppressor), power supplies of the magnetic field, ion pumps and diagnostics.

The electronics of HVT is divided on 3 separate units. The most power consuming is collector power supply (PS), with up to 15 kW output power, therefore it was designed as standalone unit equipped with an oil force-cooling system. The power supplies of magnetic coils and power supplies of remaining electrodes (SGF) are located at opposed to collector power supply side on HVT bottom.

The electrostatic column consists of individual section (see Fig.2). Each section contains two high-voltage power supplies with maximum voltage 30 kV and current 1 mA, two coils forming the magnetic field of the acceleration tubes, the section of the cascade transformer for electronic device powering, the electronic module and oil tubes for cooling all elements. The electronic module of the section is located in the special metal box for preventing spark effects. Each section is installed on the polyamide isolators. The thickness of one section is 40 mm. The distance between sections is 20 mm. Each section is surrounded by a guard ring. The electrostatic column is located in the high pressure vessel with 6 bar of SF6.

The energy for the section is provided with section transformer (see Fig. 2). The system consists of 33 transformers with cascaded connection. The electrical energy is transmitted from section to section from the ground to high-voltage terminal. The transformers are located inside the vessel with oil for isolation and cooling. Along this way the energy is consumed by the regular high-voltage section.

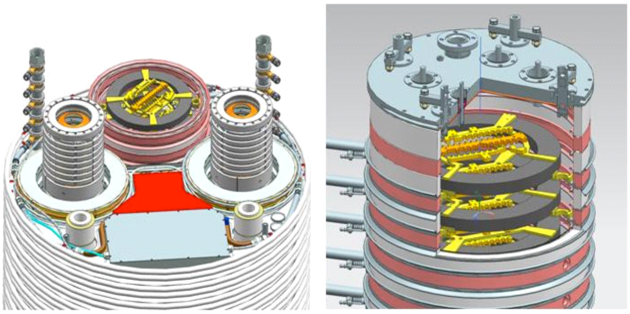

Figure 2: Design of the HV section (left picture) and cascade transformer (right picture).

The main problem of such decision is leakage magnetic field from the transformer core that can be solved with special compensative capacitance. The transformer column has the special spark-gap system for the safety at gas breakdown processes.

The requirement to operate in the wide energy range from 25 keV to 2 MeV leads to necessity of the strong longitudinal magnetic field along whole trajectory from the gun to the collector. So, the bend magnets and linear magnets contain solenoid coils. The section with large coils intends 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.

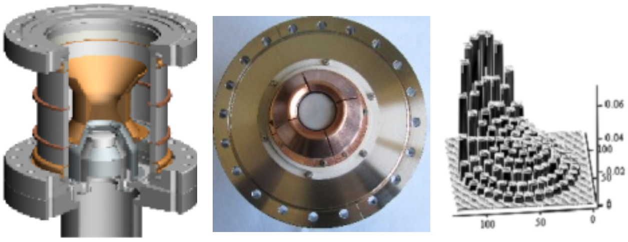

Figure 3: Design of the electron gun and 4-sectors control electrode. The right picture shows the distribution of the electron current when the control voltage is applied to the single sector.

DIAGNOSTICS AND COMMISSIONING

The beam line is equipped with several types of the beam diagnostics. The electron beam trajectory is measured by 12 BPMs. The effective cooling demands minimization of the electron angles and envelope oscillation of the beam. For this purpose the special electron gun with 4-sectors control electrode was designed and manufactured (see Fig. 3). The modulation signal AC can be applied to each sector of the control electrode. So, the position of one quadrant sector of the electron beam can be measured by BPM system. Comparing the positions of each sectors from BPM to BPM or the sector positions in the single BPM between the different values of the corrector coils it is possible to analyze the optics of the electron beam in the transport channel.

The Fig. 4 shows the simple verification of the possibility of four-sector BPM system. The size of the electron beam changes subject to the DC voltage applied to the control electrode. The negative voltage decreases the radius of the electron beam. The Fig. 5 shows the possibility of this system to measure the rotation of the electron beam induced by the space charge. One can see that the rotation angle accumulates from the first to last BPM and there is a dependence of rotation angle from the electron current.

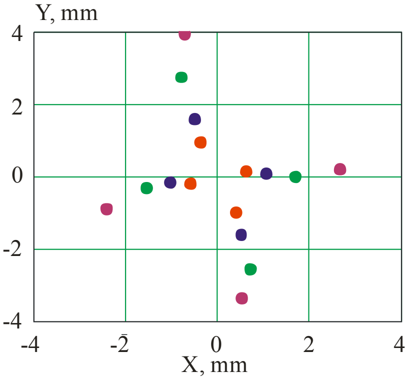

Figure 4: Beam size changing at the different DC voltage applied to the control electrode. The voltages of the control electrode are 0, -0.2, -0.4, -0.6 kV for points from outside to inside. The voltage of the anode is 1.4 kV.

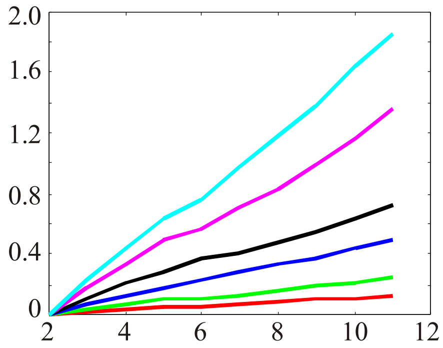

Figure 5: Rotation angle accumulating along electron trajectory versus BPM number, Y –axis is radians. The electron current is change from 50 to 400 mA (the curve from bottom to top).

The control of the beam shape can be done independently by a set of the Faraday cups located in 9 (see Fig. 1). The electron beam is shifted by the correctors on the diagnostics device. In order to minimize the load of the electrostatic generator the electron beam was modulated in the pulse mode (5 μs pulse at 20 Hz repetition rate). So, the electrostatic generator is able to work in nominal regime because the average DC current to the ground is small enough. Fig. shows the measured profile with the parameters of the electron gun Ugrid=0, Uanode=1 kV, Jimpulse≈30 mA that corresponds to the calculation and previous measurement with analogous gun.

The electron beam should stay for hours at the nominal energy and currents. The 6 day and night commissioning of the electron cooler with energy 1 MeV and current 200 mA shows the acceptable reliability level of the device.

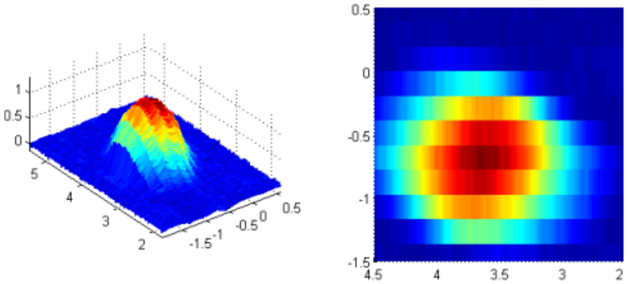

Figure 6: Profile of the electron beam measured with set of Faraday cups.

CONCLUSION

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 and Juelich. The strong surprises aren't observed. The cooling experiments in COSY were started. The conception of magnetized cooling is useful until now.

REFERENCES

[1] A.N.Skrinsky, V.V.Parkhomchuk. Physics of elementary particle and atomic nucleus. v.12 (1981), N.3, p. 557-613

[2] Ya. S. Derbenev and A. N. Skrinsky. Particle Accelerators, 1978, Vol. 8, p. 235-243.

[3] N.S. Dikansky, V.I.Kudelainwn, V.A.Lebedev et al. "Ultimate possibilities of electron cooling". BINP, Preprint 88-61.

[4] V.V.Parkhomchuk. Nucl. Instr. Meth. A 441 (2000), p. 9-17.

[5] A. Fedotov, D. Bruhwiler, A.Sidorin et al. Physical Review Special Topics - Accelerators and Beams 9, 074401 (2006).

[6] P. Beller, K. Beckert, B. Franzke et al.Nuclear Instruments and Methods in Physics Research A 532 (2004) p.427–432.

[7] T. Shirai, S. Fujimoto, M. Ikegami et al Proceedings of COOL 2007, Bad Kreuznach, Germany THM1I02.

[8] FAIR Conceptual Design Report (CDR), GSI 2004, https://www-alt.gsi.de/documents/DOC-2004-Mar-201.html.