THE FIRST COMMISSION RESULTS OF THE HIGH VOLTAGE MAGNETIZED COOLER FOR COSY

V.B. Reva, N. Alinovsky, A.M. Batrakov, T.V. Bedareva, E.A. Bekhtenev, O.V. Belikov, V. N. Bocharov, V.V. Borodich, M.I. Bryzgunov, A.V. Bubley, V.A. Chekavinskiy, V.G. Cheskidov, B.A. Dovzhenko, A.I. Erokhin, G. A. Fatkin, M.G. Fedotov, A.D. Goncharov, K.M. Gorchakov, V. K. Gosteev, I.A. Gusev, A.V. Ivanov, G.V. Karpov, Yu.I. Koisin, M.N. Kondaurov, A.M. Kryuchkov, AD. Lisitsyn, I.A. Lopatkin, V.R. Mamkin, A.S. Medvedko, V.M. Panasyuk, V.V. Parkhomchuk, I.V. Poletaev, V.A. Polukhin, AYu. Protopopov, D.N. Pureskin, A.A. Putmakov, E.P. Semenov, D.V. Senkov, D.N. Skorobogatov, N.P. Zapiatkin BINP SB RAS, Novosibirsk, Russia

Abstract

The electron cooler of a 2 MEV for COSY storage ring FZJ is assembling in BINP. The cooling section 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 0.1(0.025)-2 MeV. The electrostatic accelerator consists of 34 individual unify section. Each section contains two HV power supply (plus/minus 30 kV) and power supply of the magnetic coils. The electrical power to each section is provided by the cascade transformer. The cascade transformer is the set of the transformer connected in series with isolating winding. This paper describes the status of the electron cooling assembling processing;

INTRODUCTION

New generation of the accelerators for study nuclear physics at range of relativistic physics 1-8 Gev/u requires very powerful cooling to obtain high luminosity. For example the experiments with 15 GeV antiproton for investigation of meson resonances on PANDA detector require an internal hydrogen target with effective thickness 4×10^{15} hydrogen atoms per cm^2 and 10^{10} – 10^{11} antiprotons circulating in HESR. In this case the peak luminosities ranging from 2×10^{31} to 2×10^{32} cm^{-2}s^{-1} are achievable. These experiments provide to observe meson resonances in proton-antiproton annihilations. Resolution of the experiments is limited only by momentum spread in antiproton beam, which must be better than 10^{-4}.

The average momentum losses on such target (for antiprotons with energy 4 GeV) will be about $(dp/dt)/p = 4\cdot10^{-6}$ s^{-1} and heating rate of momentum spread by fluctuation of ionization losses will be near $(dp^2/dt)/p^2 = 2\cdot10^{-9}$ s^{-1}. Easy to see that to obtain momentum spread 10^{-5} – 10^{-4} we need cooling time at range

$$\tau_{cool} = 2(dp/p)^2/(dp^2/dt/p^2) = 0.1 \div 10 \text{ s}.$$

The electron cooler with energy 4.34 MeV at RECYCLER (FNAL) [1] has cooling time near 1 hour. New cooler for COSY should have few order magnitude more powerful cooling that required new technical solutions. 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. For example the electron beam density $2*10^8$ cm^{-3} (beam diameter 6 mm and current 1.5 A) magnetized with longitudinal magnetic field 2 kG will have at beam reference system drift velocity $2.7*10^6$ cm/sec. This velocity lets (at principle) to have cooling time near 0.1 sec for the beam with low angular spread $\Delta p_\perp / p = 10^{-5}$.

The basic idea of the design 2 MeV electron cooler for COSY ring is to test main features of the 4-8 MeV electron cooler for HESR GSI. The step at the energy of electron beam from 200-300 keV today to 8 MeV for HESR looks too large. The new technical solution should be tested at smaller step for example 2 MeV cooler for COSY. The design of the electron cooler for existing synchrotron COSY give additional limitation by existing building (upper points for lifting crane hook 7 m) and existing free space for cooler 6390 mm.

The structure of the 2 MeV cooler for COSY is shown in Fig. 1.

MAGNETIC SYSTEM

The optics of 8 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 has maximum value with compare to the transverse component of the magnetic fields.

The magnetic system of the cooler consists of the coils of gum and collector, accelerating/decelerating tubes, transport channels from high-voltage tank to the cooling section, cooling section and transport channel of the return way. The transport channels contains the six 90 degree bend toroidal magnets, two matching sections between high-voltage tank and transport channel, two matching section between transport channel and cooling section and six straight section for technological purpose.

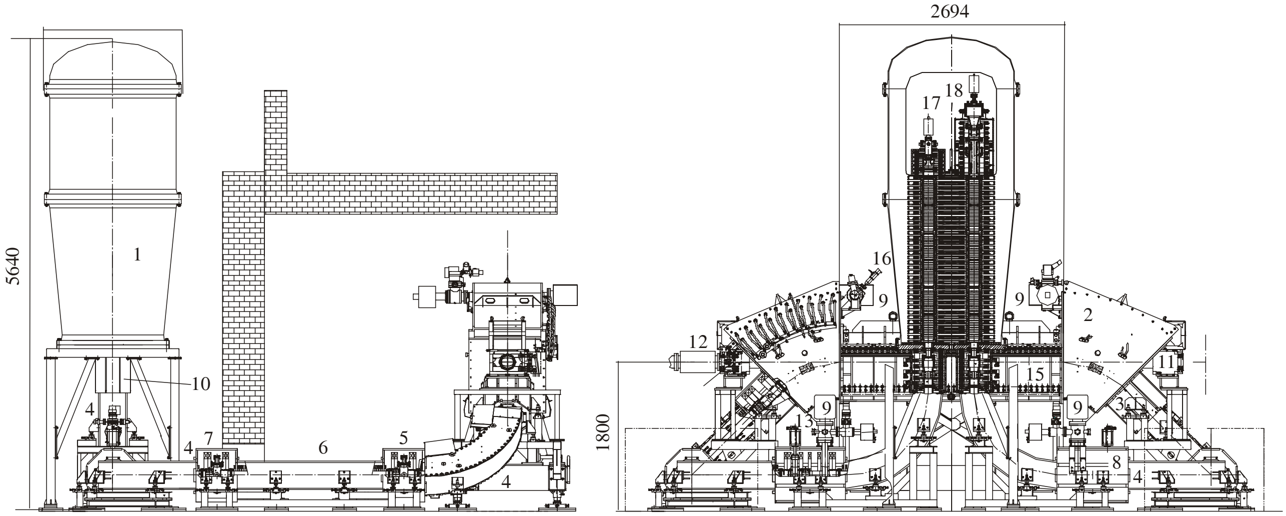

Figure 1 Sketch of the 2 MeV Cooler COSY. High voltage tank is 1, 45° toroid is 2, magnetic system of the transition section from 45° toroid to the transport channel is 3, magnetic system of the 90° bend is 4, magnetic systems of the straight line 0.5 m are 5 and 7, the straight section 1.7 m is 6, the straight section 1m is 8, the pump is 9, the transition section accelerating tube – transport is 10, the dipole correction of the ion beam is 11, the fast ramping kicker is 12, the vacuum gate is 13, the quadrupole lens of COSY ring is 14, the cooling section is 15, the rotary motion feedthrough to the vacuum for the magnetic compass probe is 16, the electron gun is 17, the electron collector is 18.

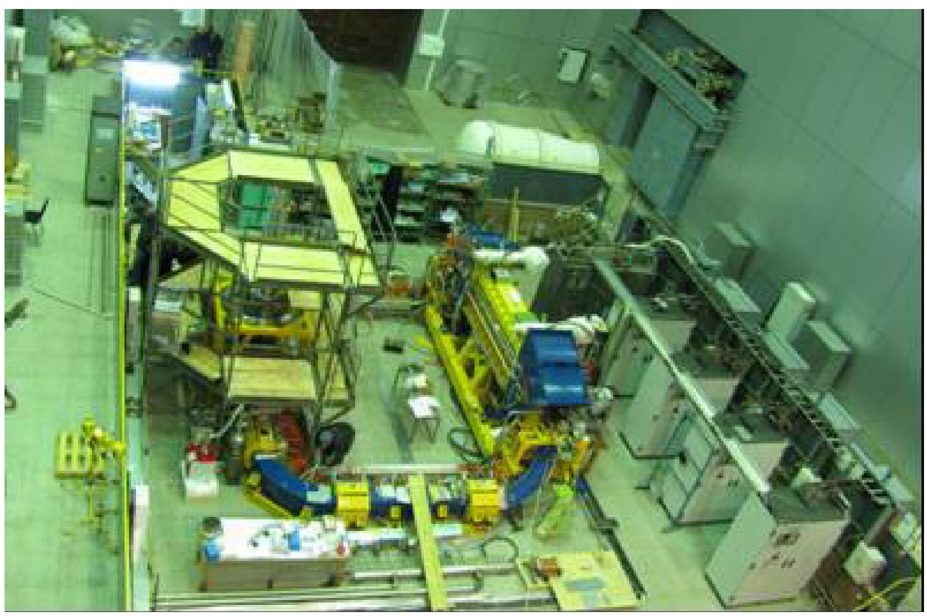

Figure 2: Photo of the electron cooler 2 MeV in assembling.

The magnetic field in the accelerating tube is taken 500 G and this value is related to the maximum power that can be transfer to a high voltage potential with help of the cascade transformer. The value in the transport channel is located in the range 0.5 kG – 1 kG. The energy 2 MeV is high enough in order to don't have the complete adiabatic motion of the electrons because the magnetic field of the bend elements is chosen to provide the length of bend equal to integer number of Larmour lengths. In such a case the kick on entry to bend is compensated by kick on leaving and the excitation of the transverse motion of the electron is small. The magnetic field in the cooling section is taken 2 kG in order to have the maximum Larmour oscillation (~ 10) of the electron during its interaction with ion in order to have the magnetized Coulomb collisions even the highest electron energy 2 MeV. The transition from accelerating tubes to transport channel is made with 7 coils with independent power supplies [2]. The transition from the transport channel to the cooling section is made with 5 coils with small regulation of the longitudinal current with regulated electrical shunt. In this region the magnetic field is strong and the electron motion is close to adiabatic so the matching can be realized by the proper location of these coils in order to minimize the amplitude of the transverse motion.

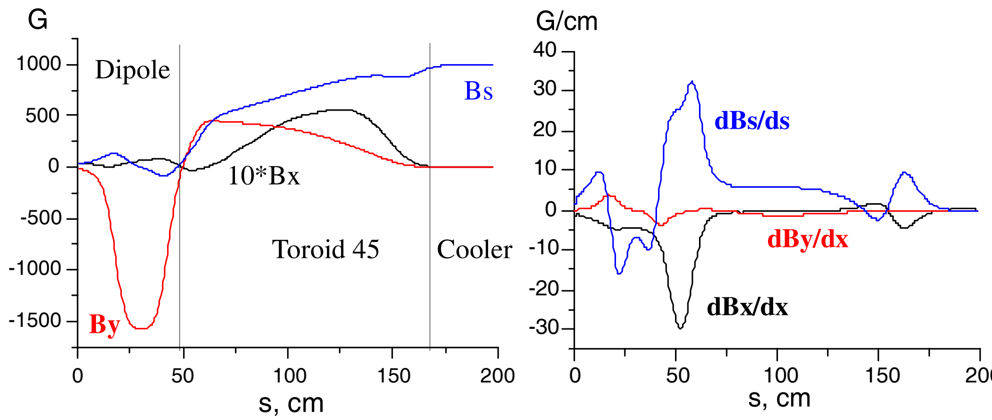

Figure 3: Magnetic field along ion channel. The currents are 175A in the cooling section, 500A in the toroid section, 200A in the dipole correction of the ion beam and 200A in the bending coils of the toroid.

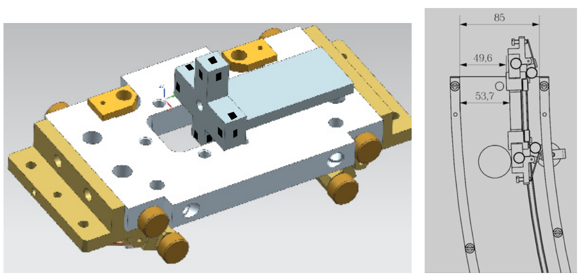

Figure 4: System of Hall probes measurements.

The tuning of the electron optics demands to knowledge of the maps of the magnetic fields for all optics elements. The special magnetic system measurement system was done for this purpose (see Fig. 4). The carriage with 12 Hall sensors is moved along the electron and ion trajectory. The sensor displacement allows measuring 3 component of the magnetic field in the 4 space point. So, the main component of the magnetic field and first derivative can be measured.

The Fig. 3 shows the primary dates of the measurement along ion orbit (dipole, toroid and entrance to the cooling section). The currents are 175A in the cooling section, 500A in the toroid section, 200A in the dipole correction of the ion beam and 200 A in the bending coils of the toroid. It is possible to see the features in the function related to the transition cooler/toroid and ion dipole corrector. The vertical field is determined by 45 degree toroid and dipole corrector. The integral of the vertical field should be compensated in normal cooler operation. The horizontal field in toroid is related to the bend magnetic field for the electron beam in the place of the ion and electron orbit interference. The Fig. 5 shows the primary data along electron orbit on the entrance to the cooler section. One can see the component of the horizontal bend magnetic field that has influence to the ion orbit.

The details of the magnetic field measurements is described in [3].

DIAGNOSTIC SYSTEM

The mapping of the magnetic field gives only the preliminary information about optics of the electron beam. The calculation of the orbit on the base of this data should be supplement with a diagnostic of the electron beam. The special electron gun with 4-sectors control electrode was designed and manufactured for this purpose. The design of the gun is shown in Fig. 6. The modulation signal can be supplied to each sector of the control electrode. So, the position of one quadrant sector of the electron beam can be measured by pick-up system. Comparing the positions of each sectors from pick-up to pick-up or the sector positions in the single pick-up between the different values of the corrector coils it is possible to analyze the optics of the electron beam in the transport channel (see Fig. 6). The coordinates of the centres of the modulation regions are marked 1,2,3 and 4. The coordinates of the centres on another pick-up are mark by prime. The distance between these coordinates indicates changing of the beam shape.

The operation of the electron gun with sector electrodes was investigated on the special test-bench gun-collector [4-5]. The perveance characteristics of the electron beam are shown in Fig. 7 for the different number sectors in the operation.

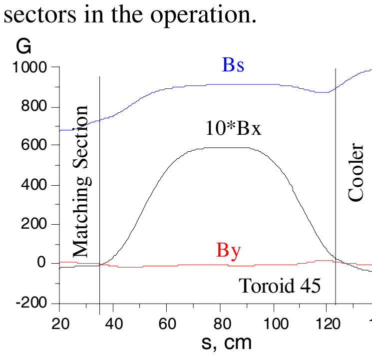

Figure 5: Magnetic fields along electron trajectory in the entrance to the cooling section.

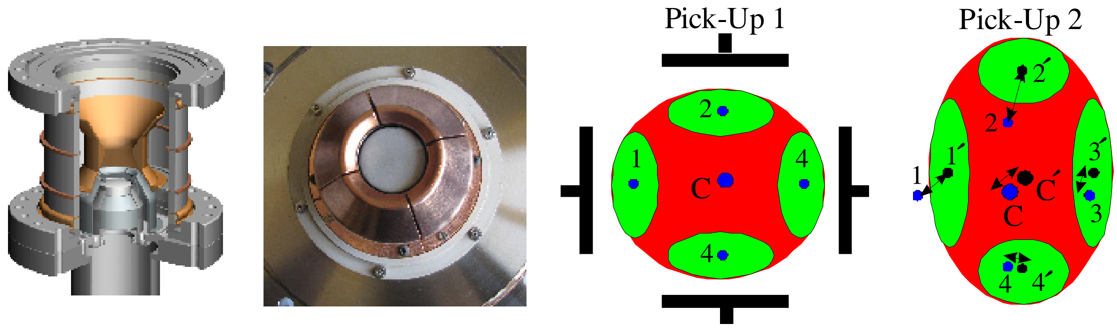

Figure 6: From left to right: sketch of the electron gun, .the photo of the sectors of the control electrode, the sketch of the measurements of the shape of the electron beam with pick-up system.

Unfortunately the test-bench wasn't equipped by the full-fledged pick-up system because the electrode of the Wien filter was used for the qualitative analyze. The figure shows the experimental results and comparing it with calculation codes. There is an agreement in the trend of the beam size changing estimated by the experimental and simulation methods but the additional improvement of the 3D calculation methods is desirable. The electron motion in the beam isn't strongly magnetized and the complete 3D simulation with space-charge effects should be done. The Fig. 8 shows that the perveance characteristic is changed at the magnetic fields that may be interpreted as not strong magnetizing dynamic of electrons in the gun.

The situation with beam profile can be cleared on the cooler with profile beam monitor consisting from many Farady cells. The electron gun has possibility to work in pulsing regime (~10 mks). During this time the control electrode is positive and the electron beam is registered by the Faraday cells in the rest time the electron beam is turned off by the negative voltage on the control electrode [6]

COLLECTOR

The main goal of the collector is minimized the number of the reflected electron from the collector. The efficiency of the collector may be improved due to installing the special filter of the velocity [4]. The region with crossed electrical and magnetic fields transmits the electron moving in one direction and strongly deflects the electrons moving in opposite direction (E x B Wien velocity filter).

The sketch of the collector is shown in Fig. 9. The collector keeps the secondary electrons with help of the magnetic and electrostatic barriers. The magnetic barriers is formed by the collector coil (see Fig. 9) connected in the opposite direction to the other coils of the collector. The electrostatic barrier is formed by combination voltage applied to collector, suppressor and pre-collector electrodes. The suppressor electrode is powered by the independent power supplies (+5 /– 3kV). The pre-collector electrode has the potential collector or one/half of the collector voltage.

The electron that leaves the collector is deflected by the Wien Filter and is absorbed by high-voltage terminal ground (Jleak2). The electrons leaving the system Wien Filter plus collector is analyzed by the special analyzing electrode (Jleak2).

It was discovered usefulness to apply to pre-collector electrode the negative voltage about 0.5·Ucoll respect to the collector. Due to large length the radial uniform electrostatic barrier is formed and it good reflects the essential part of the secondary electrons leaving collector.

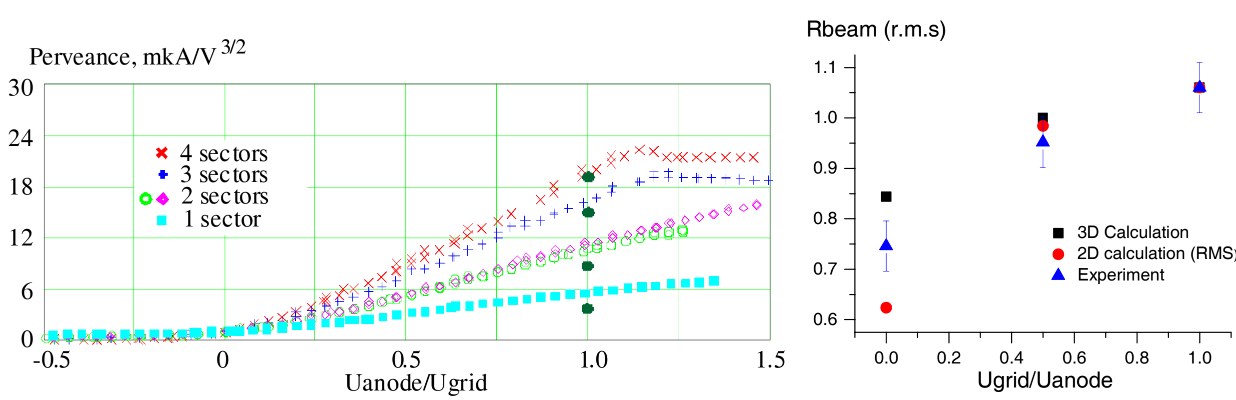

Figure 7: Perveance characteristics of the electron gun at the different number of the sectors in the operation (left picture). The comparison of the experimental observed radii of the electron beam with the computer simulations.

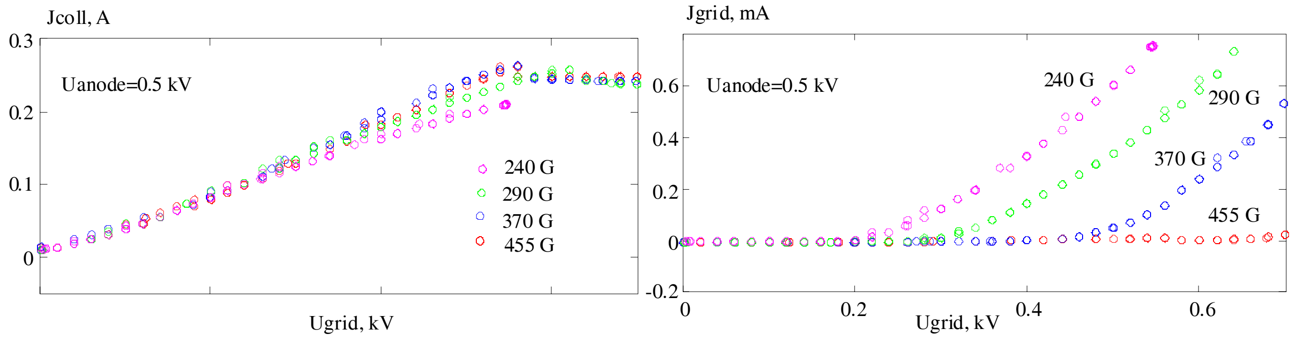

Figure 8: Electron current versus the grid voltage at the different values of the magnetic fields (left picture) and the leakage current to the grid voltage (right picture).

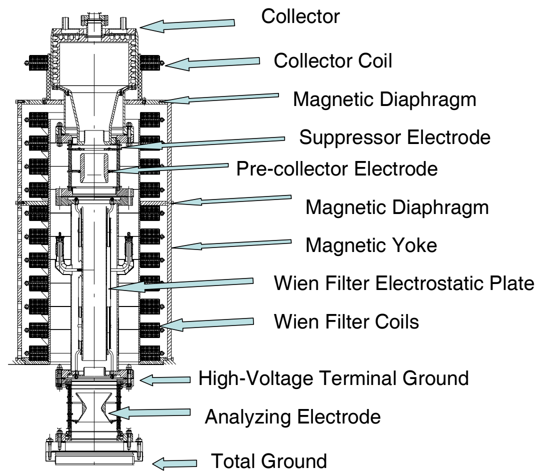

Figure 9: Collector design.

The typical curves the leakage currents from the current in the collector coil are shown in Fig. 10. The parameters of the electron gun and collector are Jcoll = 220 mA, Usup = -0.2 kV, Uan = 1.0 kV, Ugrid = 0.35 kV, Uprecoll=0.5·Ucoll. The effectiveness of the collector is $6\cdot10^{-4}$. The effectiveness of the system collector plus Wien filter is $5\cdot10^{-6}$ in this regime.

The effectiveness of the collector can be improved by the adding bend of the magnetic field in the collector. The magnetic diaphragm of the collector is circle made from two half. One half can be removed and the magnetic field is strongly turned to the other part of the diaphragm (see Fig. 11). The result of the measurements of the leakage current in the new system is shown in Fig. 12. One can see that the collector efficiency of the collector and filter is about $5\cdot10^{-6}$ in the axial symmetric case. But the efficiency of the system with the magnetic bend is better than 10^{-6}. The efficiency of the collector only isn't changed. This regime of the collector operation is closed to be proposed in [7].

The details of the experiments with collector system are described in [4].

CASCADE TRANSFORMER

The key problem of the accelerating/decelerating column is transfer energy to 33 sections, gun and collectors are located at high voltage potential. The base idea of the power supply is based on idea of a high frequency cascaded resonant transformer. 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. Along this way the energy is consumed by the regular high-voltage section. The main problem of such decision is leakage inductance of the transformers. They are connected in series and the voltage from power supply is divided between inductance leakage and a useful load. In order to solve this problem the special compensative capacitance is used. The impedance of leakage inductance is decreased significantly on the resonance frequency.

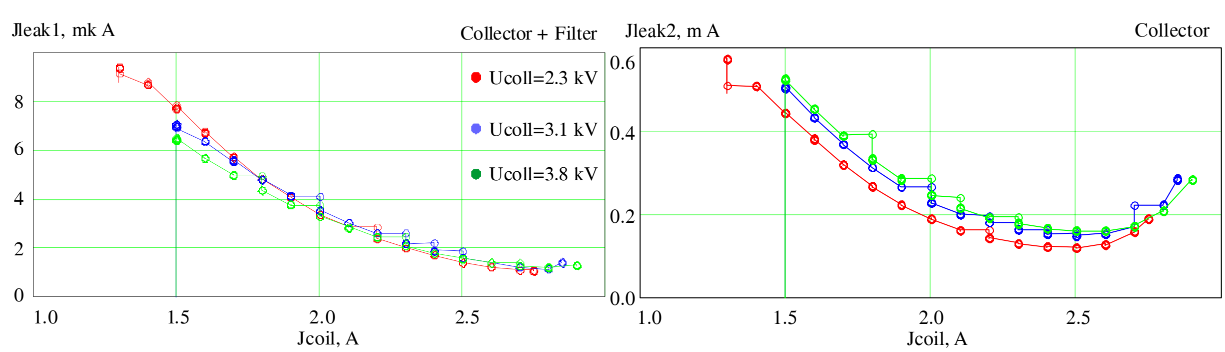

Figure 10: Leakage current from the system collector plus Wien filter (left picture) and the leakage current from the collector only versus the current in the collector coil.

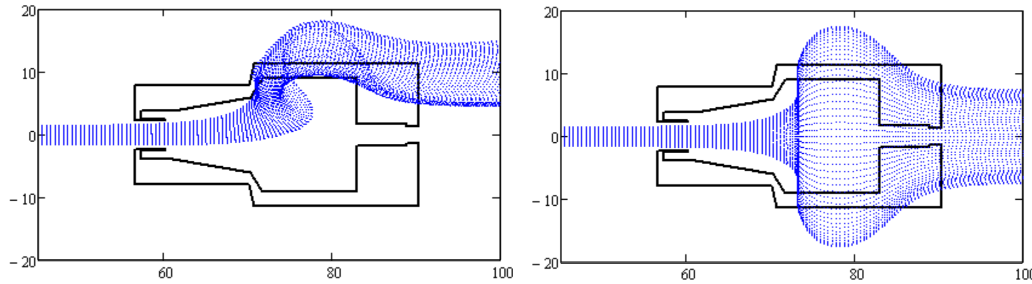

Figure 11: Distribution of the magnetic field in the collector configuration with bending field (left picture) and the collector configuration in the symmetrical case. The points are force lines of the magnetic field.

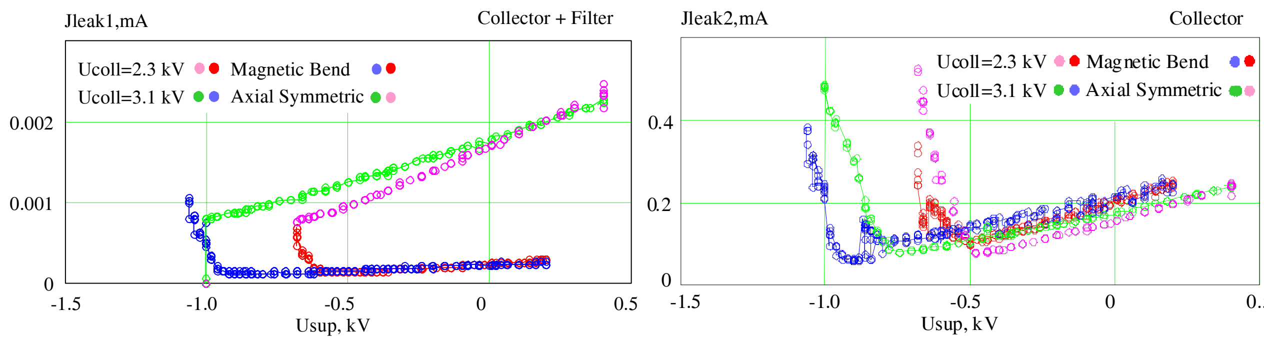

Figure 12: Leakage currents in the symmetrical configuration of the collector and with bend component of the magnetic field.

The figure shows the coefficient of the transfer of power as function of the generator frequency. The experiments is made on the complete transformer column containing 33 section. At the r.m.s. voltage 700 V from power supply of the cascade transformer the output power will be 20 kWt.

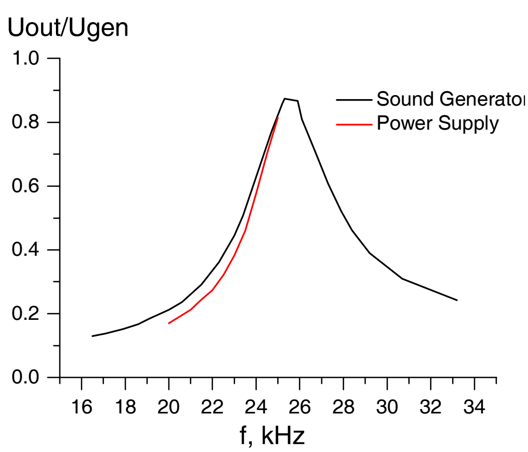

Figure 13: Coefficient of the energy transfer .of 33 sections of the cascade transformer. The load is 20 Ohm.

CONCLUSION

The key problems of the electron cooler 2 MeV is experimentally verified in the different test-benches [3-5,8]. The strong surprises aren't observed and the elements of cooler are ready to continue assembly and commissioning.

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