ELECTRON COLLECTOR FOR 2 MEV ELECTRON COOLER FOR COSY

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Abstract

New electron collector for 2 MeV electron cooler for COSY ring is presented. In electron coolers efficiency of collector is important for high voltage power supply. In 2 MeV cooler for COSY it is also important from the point of view of radiation safety because secondary electrons, reflected from the collector go back to accelerating tube. Besides radiation effect it can cause problems with vacuum and electric strength. The collector presented in the article is supplemented with Wien filter which allows increase efficiency of the system by deflection secondary electron flux in crossed transverse electric and magnetic fields. Results of calculation and experimental results achieved on special test bench are presented.

INTRODUCTION

Bad efficiency of recuperation in electron cooling systems results in higher current of lost of full energy electrons. It needs higher power of high voltage source that can be difficult technical task. Also electrons reflected from the collector and accelerated in accelerating tube are source of radiation because they hit a wall of vacuum chamber on full energy. Besides the problems, related with the radiation safety, the radiation can cause problems in reaching good vacuum conditions and decrease electric strength of the cooler. In previous coolers produced in BINP for IMP (China) and CERN the efficiency was improved with the help of special electrostatic bending plates installed in the toroid parts of the coolers [1]. Electrons reflected from collector move from collector to gun solenoid and then back to collector where they can be absorbed. These plates allow to increase efficiency of cooler recuperation from 10^{-3} to 10^{-6}. But in 2 MeV cooler for COSY shape of the magnetic system and high energy of electrons make using of such method very complicated. In this case one should improve collector's efficiency.

In the 2 MeV electron cooler for COSY new construction of collector was proposed. From calculations, its efficiency is about 10^{-3} that is not enough for the high voltage cooler, where maximum electron current is 3 A. In order to increase efficiency of recuperation a Wien filter was installed before the collector for suppression of secondary electron flux reflected from the collector

COLLECTOR

The collector design is shown in Fig. 1. The electron beam coming from the Wien filter (1), passes through collector electrode (2) and suppressor (3) and enters inside the collector (4). Due to magnetic shield (8) and coil (9) with opposite current the beam expands and deposits on cooled collector surface (5). To provide effective pumping from the collector there is a hole with small ion pump (6). To avoid electron flux into this hole in its center a thin electrode is placed.

Adjusting current in coil (9) one can improve collector efficiency by closing in the collector electrons reflected form its surface. Moreover it allows achieve more uniform distribution of electron flux on inner surface of the collector without causing local overheating and to cool the collector more effectively.

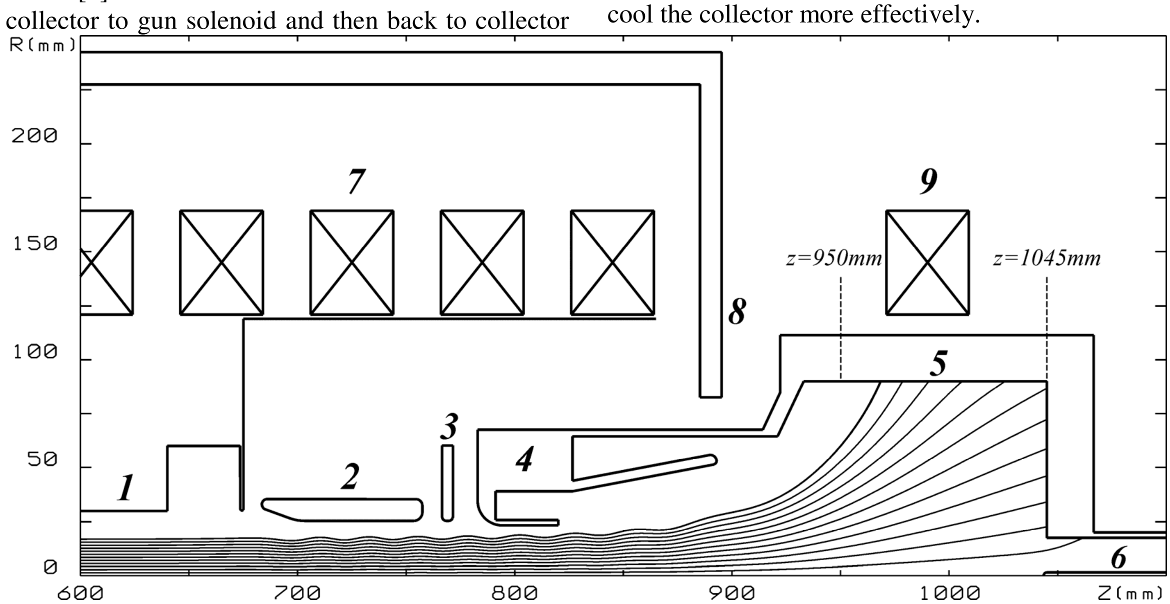

Figure 1: Collector design.

WIEN FILTER

The idea of the Wien filter is suppression of secondary electrons by crossed transverse magnetic and electric fields (fig. 2). For primary beam Lorenz and electrostatic forces compensate each other and the beam moves along axis of system to the electron collector:

$$F_{\perp} = \frac{e}{c} V_{\|} B_{\perp} - eE_{\perp} = 0 \,,$$

where $V_{||}$ - longitudinal velocity of an electron, $B_{\perp}$ and $E_{\perp}$ - transverse magnetic and electric fields.

For secondary beam, reflected from the collector, Lorenz force acts in opposite direction and resulting transverse force is a sum of electrostatic and Lorenz forces:

$$F'_{\perp} = \frac{e}{c} V_{\|} B_{\perp} + eE_{\perp} = 2\frac{e}{c} V_{\|} B_{\perp} \,.$$

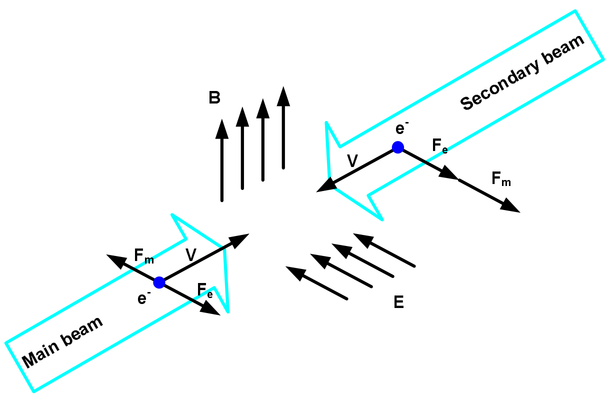

Figure 2: Wien filter.

In longitudinal magnetic field $B_{||}$ the transverse force courses secondary beam drift in the direction, perpendicular to electric field lines:

$$V_{DR} = c\frac{F_{\perp}}{eB_{\|}} = 2V_{\|}\frac{B_{\perp}}{B_{\|}} \,.$$

In our system permanent magnets were chosen to produce transverse magnetic field. Using of permanent magnets decreased possibility of tuning the filter, in comparison with additional coils, but it allowed decrease size of the filter and the magnets do not need additional power supplies.

On fig. 3 a sketch of the Wien filter is shown. The permanent magnets (1) are placed on plates of magnetic screen (2) around coils of longitudinal magnetic field (3). Vacuum chamber (4) contains electrostatic plates (5) for production of transverse electric field. The plates are connected to high voltage power supplies via special connectors (6).

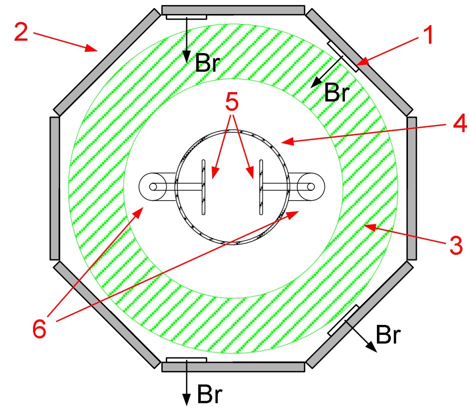

Figure 3: Sketch of Wien filter for 2 MeV cooler.

During entrance to the filter, electron is accelerated or decelerated by edge fields of the plates, that depends on coordinate of an electron. It means that in the filter electrons, flying closer to positive plate, have higher velocity than in the centre of the beam. Since Lorenz force depends on the particle velocity, resulting force for primary beam is not equal to zero for accelerated and decelerated electrons. This results in change of shape of the primary beam and can decrease perveance and efficiency of electron collector.

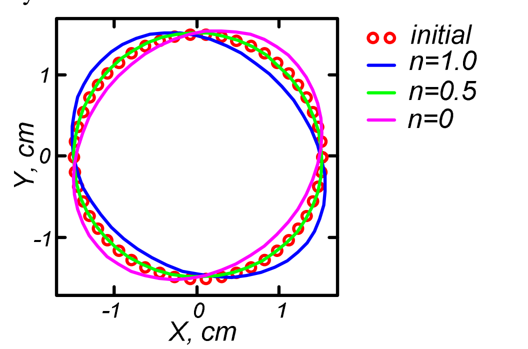

Figure 4: Change of primary beam shape in Wien filter.

In order to avoid this problem transverse magnetic field should have gradient:

$$B_x = B_{\perp}\frac{n}{R}y \,, \quad B_y = B_{\perp}\left(1 + \frac{n}{R}x\right),$$

where $R = \dfrac{pc}{eB_{\perp}}$, $n = \dfrac{1}{2\gamma^2}$, x and y – coordinates in transverse direction, γ – Lorentz factor. For low energy beam $n \approx 0.5$.

On fig. 4 one can see change of main beam shape for different values of n.

Size, magnetization and positions of the magnets were calculated with the help of the Mermaid program (produced in BINP) in order to produce field with needed parameters. On fig. 5 one can see 3D view of magnetic system of the Wien filter.

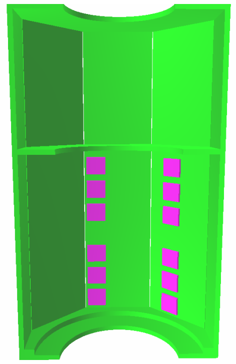

Figure 5: 3D view of magnetic system of Wien filter from Mermaid program.

Total number of magnets is 24 with Br=1.3 kG. Integral of transverse magnetic field along axis is 1400 G·cm. Length of electrostatic plates is 38 cm.

On fig. 6 the side view of vacuum chamber of the filter is shown.

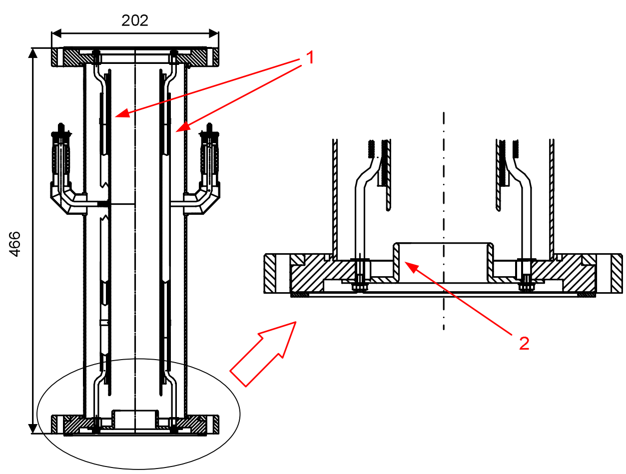

Figure 6: Vacuum chamber of Wien filter.

The chamber includes electrostatic plates (1) and secondary collector (2) which absorbs electrons reflected from the collector and deflected in Wien filter. Inner diameter of the secondary collector is 5 cm. Main beam diameter in this region is about 3 cm.

TEST BENCH

In order to test and improve work of the high voltage terminal for the 2 MeV electron cooler for COSY a special test bench was used (fig. 7). It is based on test bench which was built for tests and measurements of electron gun with variable beam profile [2].

The test bench consists of main magnetic system (1), high voltage terminal (2), electron gun (3) and central vacuum chamber (4). High voltage terminal includes magnetic coils of longitudinal magnetic field in gun and in collector (5), collector with Wien filter (6), power supplies and control electronics. It should be noted that in the cooler the gun is placed inside the high voltage terminal but in the test bench we made straight system and gun was placed in the bottom of the system. Control of the gun was made with the help of electronics of the high voltage terminal.

Measuring the efficiency of the collector in such a straight system is difficult task because reflected electrons fly to cathode region and then return back to collector. In system with Wien filter efficiency of the collector itself can be measured by measuring current which goes to secondary collector I_{sec}. Supposing that efficiency of the system with Wien filter is much better then without it one can say that all electrons reflected from the collector go to secondary collector and efficiency of collector itself is equal to I_{sec} divided to main beam current I_{coll}.

In order to measure efficiency of the collector with Wien filter a ceramic insertion with an electrode was installed under the Wien filter. Inner diameter of the electrode is 4 cm. Supposing that only secondary electrons which deflection in the filter is not enough to go to the secondary collector and electrons reflected from the secondary collector can leave the Wien filter, one can assume that most part of such electrons go to this electrode. It means that efficiency of full system is equal to current of the electrode I_{ins} divided to I_{coll}.

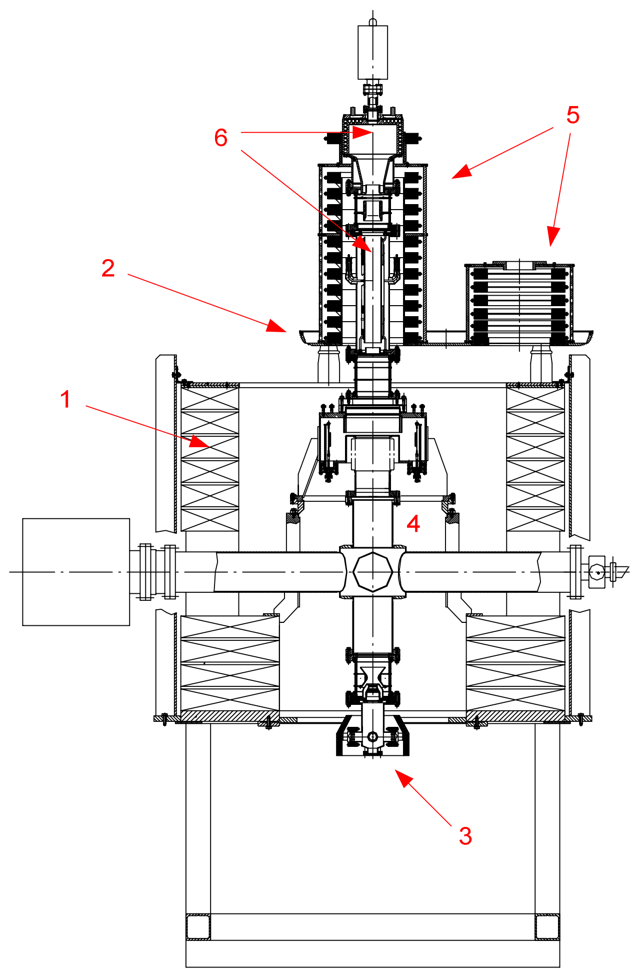

Figure 7: Test bench.

EXPERIMENTAL RESULTS

Electrons reflected from collector surface have wide energy spectra. The aim of the suppressor electrode is to produce potential barrier in order to close low energy electrons in the collector. But since the electrode is thin, the potential in axis and in edge of electron beam is different. Because of this there must be an optimum in order to close as much reflected electrons in the collector as it possible but to not reflect electrons on the edge of the main beam. Collector electrode is much thicker then suppressor and its potential in axis and in beam edge is equal. Because of this it closes all secondary electrons, which energy is lower then potential of the electrode. On fig. 8 the dependence of collector efficiency on electron beam current for different ratio between voltage of the collector and collector electrode is shown. U_{coll}=3.5 kV.

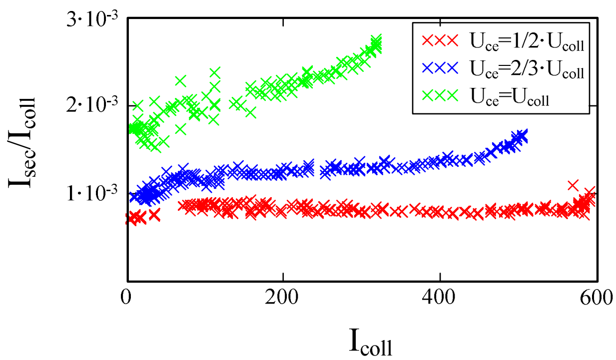

Figure 8: Dependence of efficiency of the collector itself on main beam current.

One can see that decreasing its voltage to ½ of collector voltage the efficiency of the collector improves to the factor of about 2.

On fig. 9 the dependences of efficiencies on beam current for the collector itself and for collector with Wien filter are shown.

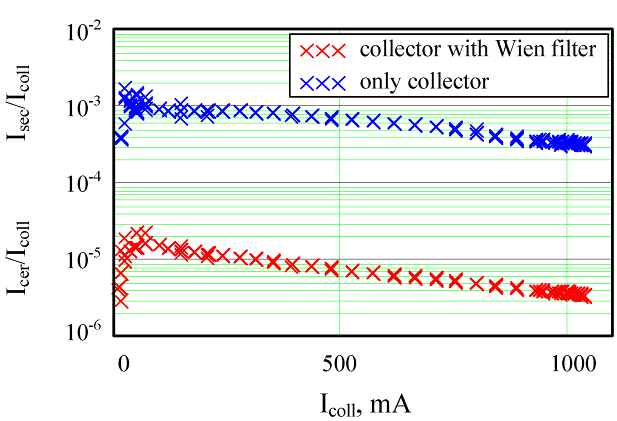

Figure 9: Dependence of efficiency of collector with Wien filter on main beam current.

Efficiency of the collector with Wien filter is about $3\cdot10^{-6}$ for current 1 A. The higher current of beam was limited by power of high voltage source which was used in the test bench.

It was said above that current in the last coil can be adjusted in order to improve efficiency of the collector . in fig. 10 a dependence of efficiency on coil current for different collector voltage is shown.

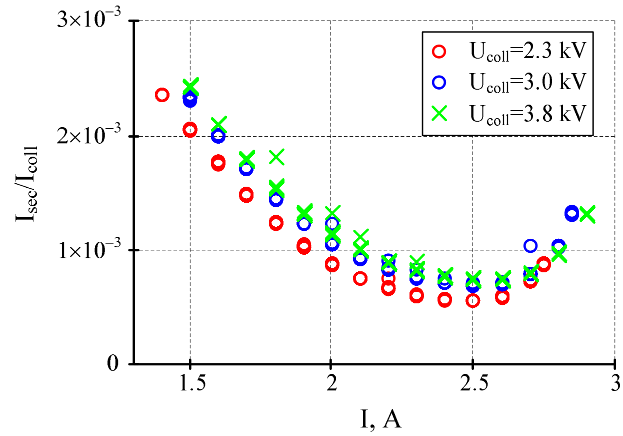

Figure 10: Dependence of efficiency on current in the last coil.

Form the figure one can see that adjusting current in the last coil the efficiency of the collector can be improved to a factor of ≈3.

CONCLUSION

Collector with Wien filter can significantly improve efficiency of recuperation of electron cooling system. On system described in the work efficiency $3\cdot10^{-6}$ was reached for main beam current 1 A.

Disadvantages of such system are using of additional high voltage power supplies for electrostatic plates of the filter, increasing of size of the system and complication of magnetic system in order to produce transverse magnetic and electric fields.

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