COLLECTOR FOR ELECTRON COOLING SYSTEMS WITH SUPPRESSION OF REFLECTED ELECTRON FLUX

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Abstract

Results of testing of the collector with Wien filter in the 2 MeV electron cooling system for COSY synchrotron are presented. Efficiency of a collector in high voltage electron cooling devices is important from the point of view of the load on high voltage power supply, radiation safety and vacuum conditions in the system. The collector for 2 MeV COSY cooler 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 tests show that such solution provides efficiency of recuperation in the cooler up to 10^{-5}. After tests some changes were made in the construction of the Wien filter to improve quality of the collector performance.

INTRODUCTION

Feature of the electron cooling is that during cooling process electron beam almost doesn't change its energy. It means that after interaction with ion beam electrons with sufficiently high energy must be utilized, that is serious technical task. To avoid this problem the method of recuperation of electron beam energy is used in electron cooling devices. An idea of the method is to decrease electron beam energy in electrostatic tube which is connected to the same high voltage power supply (PS) which is used for acceleration of electrons. After that electron beam is directed to a special collector where they are absorbed by its surface. Usual energy of electrons absorbed in a collector is 1÷5 kV and it is defined by a special collector PS.

The method allows decrease power consumption of the high voltage PS because it determined only by leakage current from the high voltage terminal to the ground. As a result it allows simplify construction of the high voltage PS Collector PS usually is more powerful but its operation voltage is several kV.

The most important cause of appearance of the leakage current from high voltage terminal is losses of full energy electrons (I_{leak}). The most part of such electrons are secondary particles reflected from a collector. The ratio of I_{leak}/ I_{beam} (where I_{beam} – main beam current) is called efficiency of recuperation.

Besides increasing of load to high voltage PS bad efficiency of recuperation in electron cooling systems can cause other problems. Full energy electrons which hit wall of vacuum chamber are source of radiation. Besides worsen of radiation safety it can cause problems in reaching good vacuum conditions and decrease electric strength of the cooler.

In coolers EC-35, EC-40 and EC-300 produced in BINP for IMP (China) and CERN the efficiency was improved with the help of special electrostatic bending plates installed in toroid parts of the coolers [1]. Electrons reflected from collector move from collector to gun solenoid and then back to collector where it 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 magnetic system and high energy of electrons make using of such method very complicated. In this case one should improve collector efficiency.

In the work [2] the best efficiency of ordinary axially symmetric collector with electrostatic and magnetic closing of secondary electrons was estimated and its value is about 10^{-4}. For high voltage electron coolers such efficiency is not enough and for the 2 MeV cooler needed value is about 10^{-5} [3]. For this a new collector with suppression of secondary electrons by Wien filter was designed [4].

COLLECTOR WITH WIEN FILTER

The main idea of the collector with Wien filter is to install a special insertion with crossed transverse electric and magnetic fields before ordinary collector (Fig. 1).

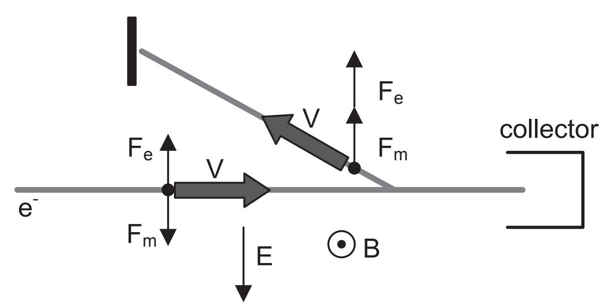

Figure 1: Principle of the collector with Wien filter work.

For main beam action of fields compensate each other but for secondary beam, which moves back, magnetic field acts in opposite direction and secondary beam is deflected to a special electrode (secondary collector).

In the 2 MeV cooler the collector with Wien filter is placed in longitudinal magnetic field that is related with features of the cooler. The field makes the secondary beam move in direction parallel to electrostatic plates protecting them from electrons of the beam.

The sketch of the collector with Wien filter for the 2 MeV cooler is shown in Fig. 2. Collector itself (i.e. collector without Wien filter) is based on construction used in previous coolers produced in BINP.

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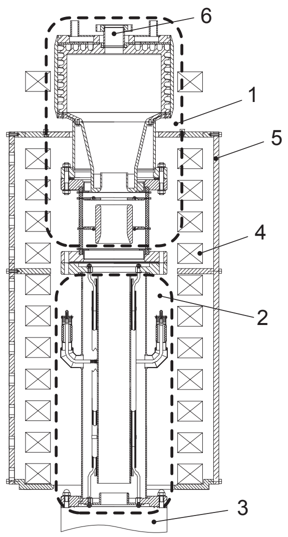

Figure 2: Sketch of the collector with Wien filter. 1-collector itself with the suppressor and pre-collector electrodes, 2 – vacuum chamber of the Wien filter, 3 – electrostatic tube, 4 – coil for longitudinal magnetic field, 5 – magnetic shield, 6 – flange for additional vacuum pumping.

Collector solenoid consists of 12 coils: 11 coils in magnetic shield and one last coil with opposite current. The coil provides more uniform distribution of electron flux on the collector surface to avoid its local overheat and to increase efficiency of magnetic closing of secondary electrons.

In Fig. 3 a part of the magnetic screen with permanent magnets and top view of the Wien filter are shown. Permanent magnets were chosen to produce transverse magnetic field in the filter. Such solution decreases size of the system and exclude additional PS.

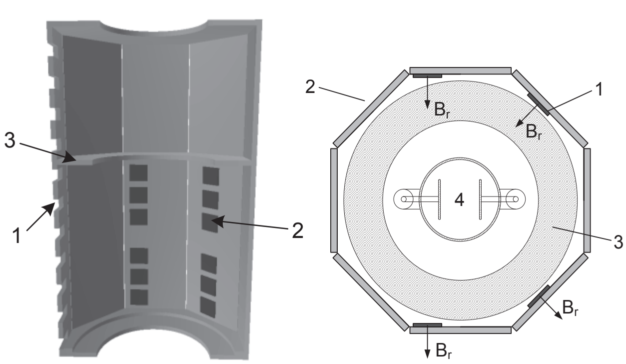

Figure 3: Left – magnetic shield with permanent magnets: 1 – holes for cooling of solenoid, 2 – permanent magnets, 3 – magnetic diaphragm. Right – top view of the Wien filter. 1 – permanent magnets, 2 – magnetic shield, 3 – solenoid for longitudinal magnetic field, 4 – electrostatic plates.

In Fig. 4 results of calculation of main beam shape after passing through the filter for different values of current are shown.

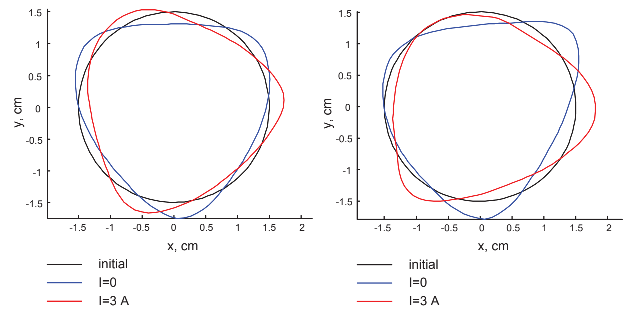

Figure 4: Main beam shape after passing the Wien filter for different values of beam current. Left – electron energy is E=20 keV, right – E=7 keV.

The results show that the space charge almost doesn't influence on the beam shape and only rotate it relative to its axis. Changes of beam shape are results of the inhomogeneity of electric filed in the filter. After experiments in the BINP shape of the plates was changed in order to improve the homogeneity.

In Fig. 5 calculated shape of secondary electron beam after passing the filter is shown.

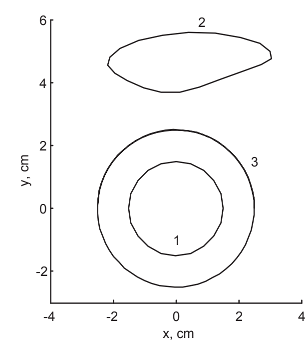

Figure 5: Shape of secondary beam after passing though the Wien filter. 1 – initial shape, 2 – shape after passing, 3 – internal size of the secondary collector.

One can see that transverse magnetic filed in strong enough to shift the beam to the secondary collector.

EXPERIMENTAL RESULTS

First tests of the collector were made on the special test bench [4]. In Fig. 6 dependences of the collector itself and combined collector efficiencies on beam current are shown. One can see that reached value of its efficiency was about $3\cdot10^{-6}$ and for high current it increases because of additional closing of secondary electrons by space charge of the main beam.

After installation in the 2 MeV cooler the collector with Wien filter was tested in its operational regime.

As it was said the filter changes beams shape. It can decrease efficiency of collector itself and of combined collector with Wien filter. In Fig. 7 dependences of efficiencies of the collector itself and combined collector on beam shape (parameter Ugride/Uanode) are shown.

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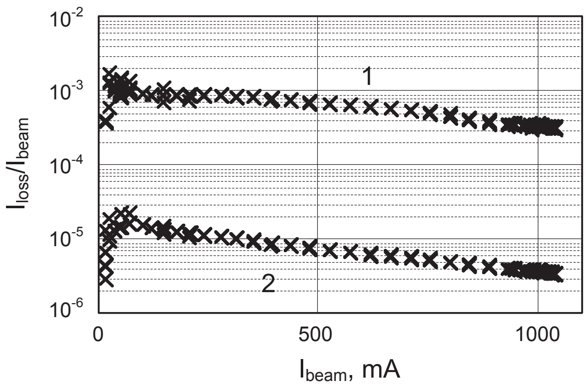

Figure 6: Dependences of the collector itself (1) and combined collector (2) efficiencies on beam current.

Small values of the parameter Ugride/Uanode correspond to small size of beam and parabolic distribution of current density [5]. For high values it has minimum density in center and maximum near the edges.

From the figure one can see that the lager density on beam edges the worse efficiency of the collector. Moreover, for high current (300 mA) beam space charge starts to influence on the efficiency by reflecting of electrons of the main beam. But efficiency of combined collector almost doesn't depend on beam current.

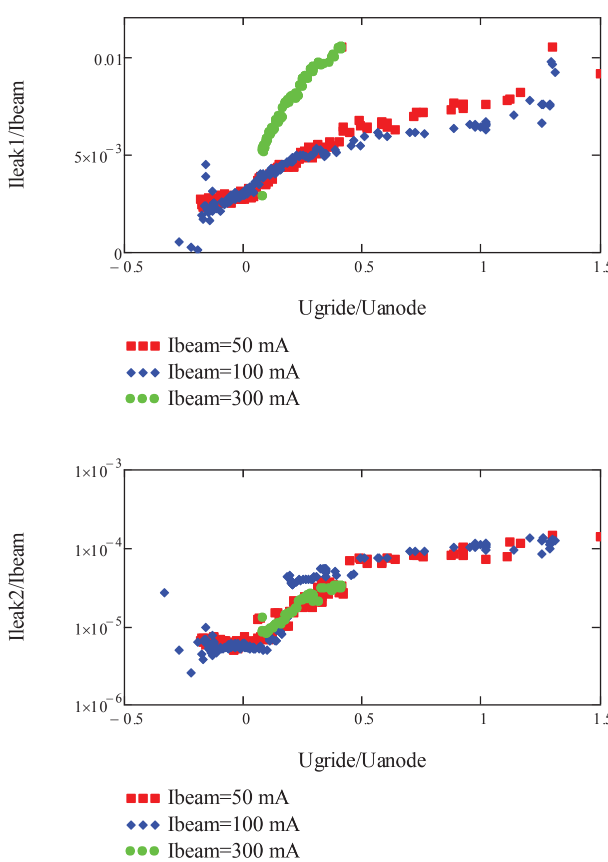

Figure 7: Dependences of efficiencies of the collector itself and combined collector on beam shape.

In Fig. 8 dependences of leak current on voltage between plates of the Wien filter are shown. Such procedure allows to measure aperture of the filter in one dimension by shifting the beam in transverse direction. U0 is the voltage which corresponds to the center of the collector.

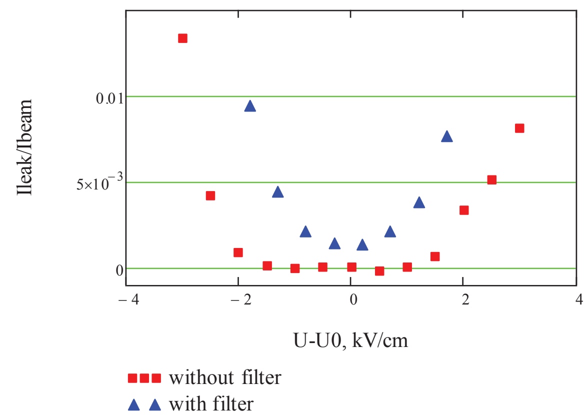

Figure 8: Dependences of leak current on voltage between plates of the Wien filter.

From the figure one can see that with filter the aperture is smaller. It also happens because of beam shape changes which increase effective size of the beam.

As it was said the current in last coil can be adjusted in order to improve efficiency of the collector. In Fig. 9 a dependence of efficiency on coil current for different collector voltage is shown.

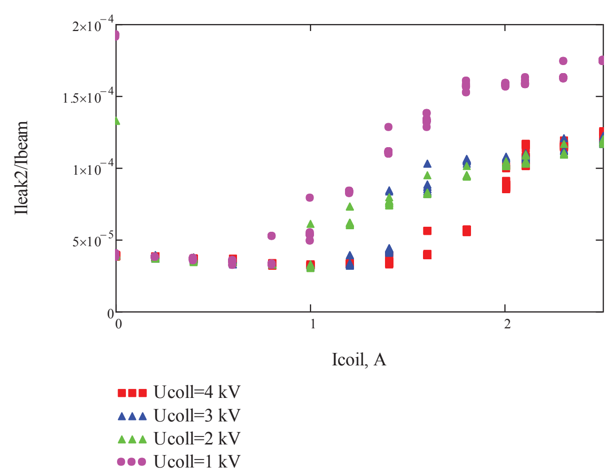

Figure 9: Dependences combined collector efficiency on current in the last coil.

From the figure one can see that for every voltage of the collector there is an optimum value of the current in the last coil. Moreover, the higher voltage the higher optimum current because for electrons with higher energy in the collector higher magnetic field is needed to bend their trajectories.

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In Figs. 10 – 12 dependences of the collector itself and combined collector efficiencies on beam current for different operational energies are shown.

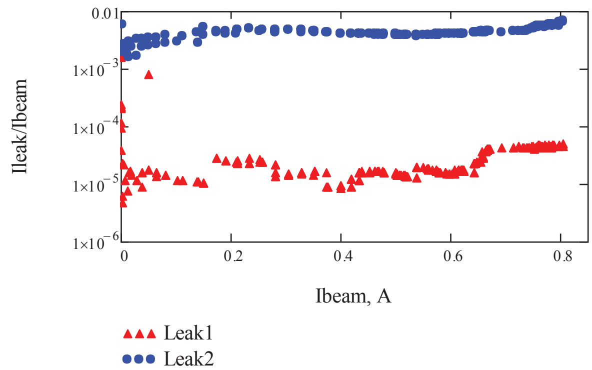

Figure 10: Dependences of the collector itself and combined collector efficiencies on beam current for 150 keV beam.

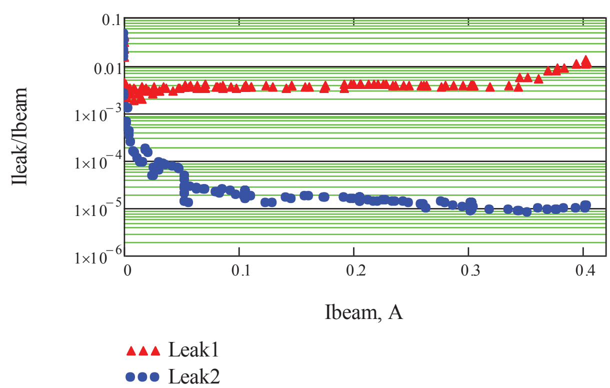

Figure 11: Dependences of the collector itself and combined collector efficiencies on beam current for 1 MeV beam.

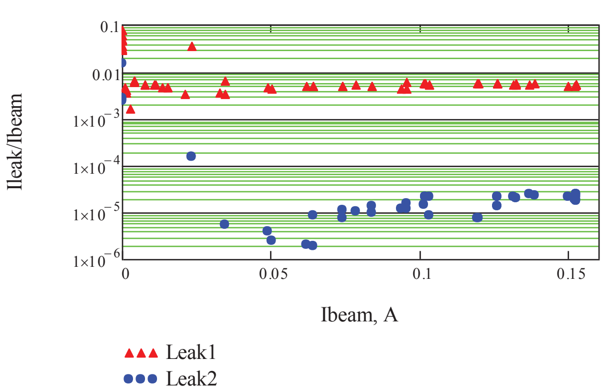

Figure 12: Dependences of the collector itself and combined collector efficiencies on beam current for 1.5 MeV beam.

From the figures one can see that efficiency of the collector is about 10^{-5}.

Worsening of the efficiency in comparison with results from the test bench can be explained by not ideal beam trajectory in the cooler or by ionization of residual gas.

CONCLUSION

Collector with Wien filter improves efficiency of recuperation of electron cooling system. In the test bench the efficiency was about $3\cdot10^{-6}$. In the 2 MeV cooler for COSY the efficiency is worse but it is about 10^{-5} that is enough from the point of view of high voltage PS load and electric strength.

Main disadvantages of such system is using of additional high voltage power supplies for electrostatic plates of the filter and increasing of the collector size.

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