WIEN FILTER AS A SPIN ROTATOR AT LOW ENERGY *

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Abstract

The Wien filter is well known as a common energy analyzer and is also used more and more as a compact variant of a spin rotator at low energy for electrons. The Wien filter is based on homogenous magnetic and electric fields which are perpendicular to each other and transverse to the direction of the electrons. The rotation of the spin vector is caused by the magnetic field. If the force equilibrium condition is fulfilled the beam should not be deflected at the Wien filter. Simulations show that in the fringe fields the electrons get a kick. Therefore full 3D simulations of the electromagnetic fields and beam dynamics simulations are studied in detail at the example of the Wien filter at the new polarized 100 keV electron injector at the S-DALINAC. The results of the simulations with CST Design Environment$^{\mathrm{TM}}$ and V-Code are presented.

INTRODUCTION

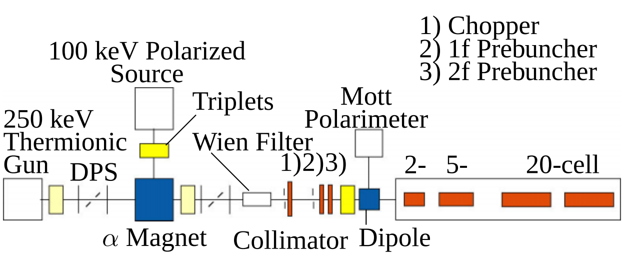

Figure 1: Sketch of the S-DALINAC injector in the accelerator hall.

A new polarized source completes the superconducting recirculating linear electron accelerator S-DALINAC [1]. Therefore the warm injector has to be redesigned. The recent status is given see in Fig. 1. Longitudinal polarized electrons generated by a circular polarized laser at a GaAs strained photocathode are focused by a vertical triplet and bended by an alpha magnet into the horizontal beam line. After passing the differential pumping stage and the Wien filter the electrons are bunched by a chopper/prebuncher system and focused by another triplet. The degree of polarization of the electrons can be measured by a Mott polarimeter through a 90° sector magnet. During operation the bunch is captured by a 2-cell superconducting rf structure and accelerated to 10 MeV. An important component of the polarized injector is the Wien filter as a spin rotator because of two reasons. The first one is the measurement of the degree of polarization with a Mott polarimeter in the injector at low energy where the spin vector has to be rotated transverse to the beam direction and the second one is that at the target for the experiments the spin vector has to be in longitudinal direction. The advantage of the Wien filter setup is that the spin rotator is compact and easy to use.

A cross-section of the Wien filter is shown in Fig. 2. The whole length of the Wien filter is 430 mm. The spin vector is rotated by a homogenous transverse magnetic field, here B_x. The homogenous magnetic field is excited by a so-called window frame coil which is surrounded by a magnet yoke. At both sides magnet end mirror plates are placed to shorten the fringe fields. For no deflection in the Wien filter, a homogenous transverse electric field E_y that is perpendicular to the magnetic field is needed. The electric field is generated by two electrode plates which are designed to compensate the force of the magnetic field. If the Lorentz force equilibrium condition [2, 3] is fulfilled one gets

$$
\begin{aligned}
q \cdot \left(\vec{E} + \vec{v} \times \vec{B}\right) &\overset{!}{=} 0 \\
\vec{E} &= -\vec{v} \times \vec{B} \qquad \text{or} \\
E_y &= -v_z \cdot B_x. \qquad (1)
\end{aligned}
$$

This equation is also known as the Wien filter condition. The rotation angle of the spin vector can be obtained from the force equilibrium condition between the Lorentz force and the centripetal force:

$$
\begin{aligned}
q v_z B_x &= \frac{\gamma m_0 v_z^2}{\rho} \\
\rho &= \frac{\gamma m_0 v_z^2}{q v_z B_x} \\
\alpha &= \frac{L}{\rho} = \frac{L e B_x}{\gamma m_0 v_z} = \frac{L\omega}{v_z}, \qquad (2) \\
& \qquad (3)
\end{aligned}
$$

where L is the effective length of the Wien filter.

The polarized source at the S-DALINAC delivers electrons with E = 100 keV which is equal to β = 0.54822 or rather to γ = 1.19569. The effective length of the Wien filter is L = 381 mm. For a 90° spin rotation a magnetic flux density of $B_x = 4.6$ mT and an electric field strength of

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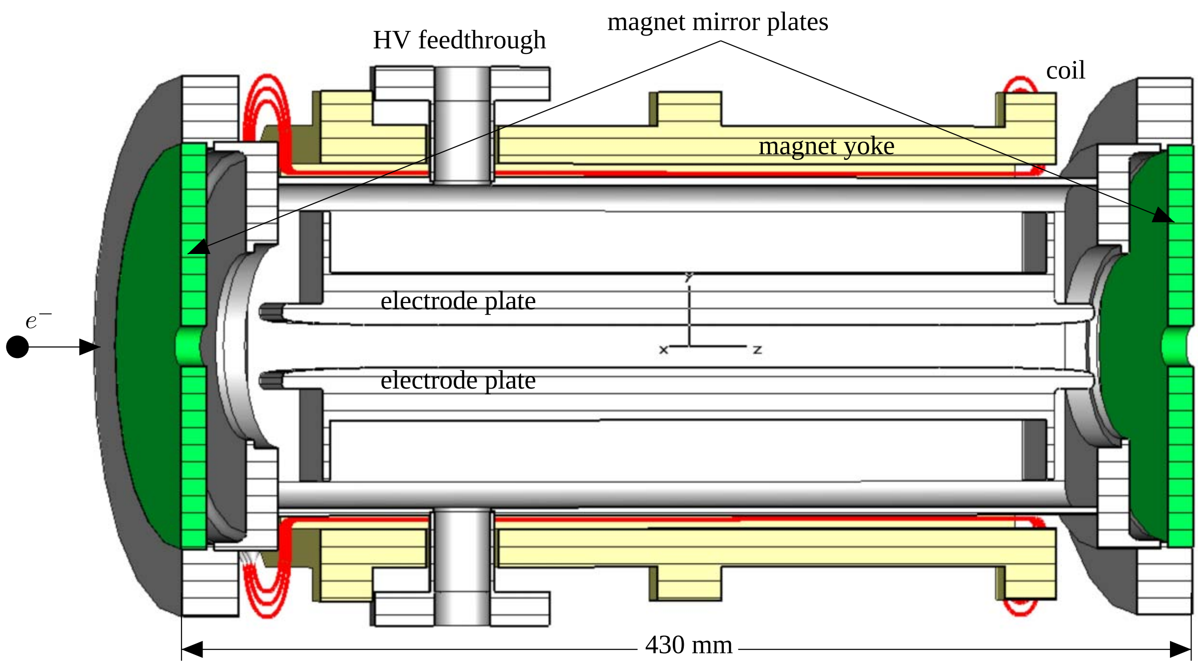

Figure 2: Cross section of the Wien filter at the S-DALINAC.

$E_y = -756$ kV/m is required. Therefore 12 kV over the 16 mm gap of the electrode plates is needed for an angular range of $\pm 90°$ spin rotation. In practice this should not be a problem, because at MAMI 25 kV over a gap of 20 mm was successfully tested [4].

SIMULATION RESULTS

If one includes the fringe fields of a finite structure the Wien filter condition is not fulfilled everywhere because the fringe fields of the electric and magnetic field have different decaying characteristic and additional longitudinal field components appear. The magnetic field is fixed by the coil construction and the mirror plates. The simulation results (Fig. 3) of the magnetic fields matches the measurement in the frame of the measurement accuracy. The bump in the magnetic fringe fields results from the magnet mirror plates which has a permeability of around 50. A degree of freedom for optimization is the form of the electrodes. As a condition for an optimal electrode structure the Lorentz force is used. The integral of the Lorentz force across the whole Wien filter has to be zero.

The magnetic fringe field of the Wien filter has a longer extension than the electric field as you can see in Fig. 3. This problem is well known [4] but the effects to the bunch are so far not simulated only measured and can kept under control.

As one can see in Fig. 4 the integral of the Lorentz force is nearly zero, but at the entrance of the Wien filter the electron bunch gets at first a kick of the magnetic field and than of the electric field and at the exit reversed.

For the beam dynamic simulations the V-Code [5, 6] is used. V-Code is based on the VLASOV equation, the beam has to be described by the phase space distribution functions of the particle density in the full six dimensional phase space. For V-Code the electric field strength E_y and magnetic field strength B_x on z-axis has to be spezified to reconstruct the full 3D fields near the axis (Fig. 3). Therefore the fields has been calculated in 3D with CST Design Environment$^{\mathrm{TM}}$ [7]. The step size of the field data

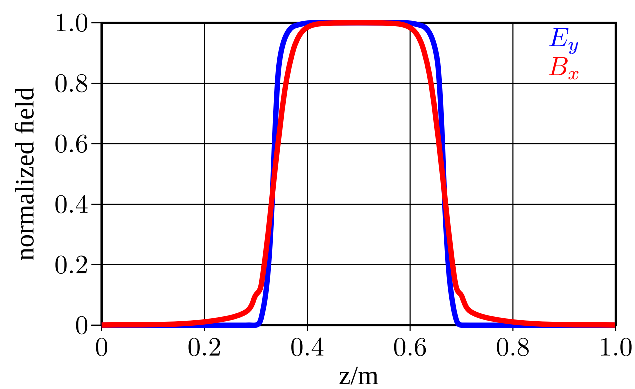

Figure 3: Normalized electric and magnetic field of Wien filter.

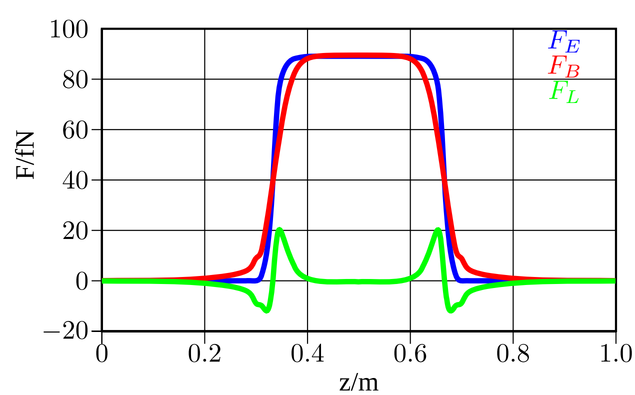

Figure 4: Forces of Wien filter.

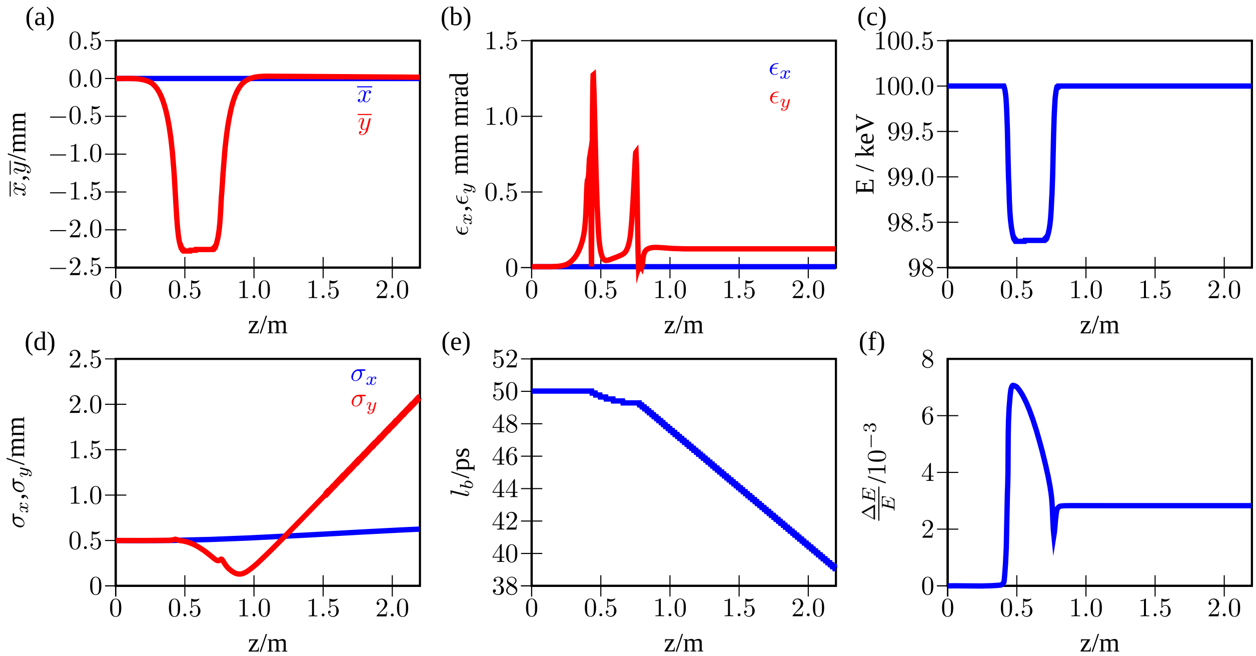

Figure 5: Transverse and longitudinal beam dynamics results through the Wien filter.

has to be 0.1 mm for getting high quality results.

For the V-Code simulation, the Wien filter is surrounded by two drift spaces before 0.1 m and behind 1.1 m. The fields of the Wien filter are calculated for one meter so that the fringe fields are faded away complete. For the calculation the start ensemble is extracted from the expected bunch parameters at the S-DALINAC. The theoretical value of the magnetic field strength of 4.6 mT for the biggest needed rotation angle of $90°$ is set. The electric field strength is around -750 kV/m which is less than theoretical calculated. Fig. 5 shows the important beam dynamics attributes. For the x coordinate the Wien filter works as a drift space as expected [3]. For the y coordinates the bunch is deflected from the axis (Fig. 5a) over 2 mm by the fringe fields and deflected back, but behind the Wien filter one gets a little offset which has to be corrected by steerer magnets. As well the emittance (Fig. 5b) in y grows through the Wien filter. The magnification of the emittance and of the offset depends on the magnetic field strength. The higher the magnetic field strength the bigger the magnification of the emittance and of the offset. The Wien filter shows a focusing characteristic for y (Fig. 5d). In longitudinal direction the beam is bunched (Fig. 5e). In the fringe field range a longitudinal electric field component de- and accelerates the electron (Fig. 5c). The longitudinal electric field strength gets larger if the y offset of the beam axis is bigger. That causes an energy spread growth (Fig. 5f) in the bunch.

CONCLUSION

Nonlinearities and coupling between the transverse coordinates could not be found. The Wien filter shows a drift space characteristic for x and a focusing for y. The offset in y and the emittance growth in y depends on the magnetic field strength. This is coupled with the length of the Wien filter and the desired rotation angle. Therefore the shorter the Wien filter gets and the higher the rotation angle is (maximum of interest $90°$) the bigger the effects get. The longitudinal electric field component depends on the offset of the axis in y direction. Its fringe fields cause a de- and acceleration of the electrons. This results in a longitudinal focussing and magnification in the energy spread. The longitudinal effects can be minimized by a well focused bunch through the Wien filter to minimize the offset of the beam axis.

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