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 used simply and 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™ and V-Code are presented.

INTRODUCTION

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 with a Mott polarimeter in 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

$$ q \cdot \left( \vec{E} + \vec{v} \times \vec{B} \right) \equiv 0 $$

$$ \vec{E} = -\vec{v} \times \vec{B} \quad \text{or} \quad E_y = -v_z \cdot B_z. \quad (1) $$

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:

$$ qv_z B_x = \frac{\gamma m_0 v_z^2}{\rho} $$

$$ \rho = \frac{\gamma m_0 v_z^2}{qv_z B_x} $$

$$ \alpha = \frac{L}{\rho} = \frac{L \gamma m_0 v_z}{\rho} = \frac{L \omega}{v_z}, \quad (2) $$

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 $\beta = 0.54822$ or rather to $\gamma = 1.19569$. 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 $E_y = -0.07$ mV/m is needed.
$E_y = -756 \text{kV/m}$ is required. Therefore 12 kV over the 16 mm gap of the electrode plates is needed for an angular range of $\pm 90^\circ$ 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 specified to reconstruct the full 3D fields near the axis (Fig. 3). Therefore the fields has been calculated in 3D with CST Design Environment$^\text{TM}$ [7]. The step size of the field data...
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 pa-
rameters at the S-DALINAC. The theoretical value of the
magnetic field strength of 4.6 mT for the biggest needed
parameters at the S-DALINAC. The theoretical value of the
rotation angle of

\[ \theta = \frac{2.5}{z/m} \]

in \( y \) and the emittance growth in \( y \) depends on the mag-
netic 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 lon-
gitudinal 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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CONCLUSION

Nonlinearities and coupling between the transverse coor-
dinates could not be found. The Wien filter shows a drift
space characteristic for \( x \) and a focusing for \( y \). The offset

\[ \sigma_x \sigma_y \]

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