SPIN MANIPULATION AT MAMI C

V. Tioukine, K. Aulenbacher, H. Euteneuer, K.-H.Kaiser, Johannes Gutenberg-University Mainz;

S. Ratschow, Darmstadt University of Technology.

Abstract

The construction of the fourth stage of the Mainz Microtron (MAMI-C) requires improvements of spin-manipulation techniques. A first goal is to provide 90 degrees spin rotation for all extraction energies of the Harmonic Double Sided Microtron (HDSM) which forms the fourth stage of MAMI (850-1500 MeV). This can be achieved by the presently applied energy variation technique if an additional accelerating section is installed in the interface between the accelerator stage RTM3 and the HDSM which is presently under construction. On the other hand, the need for spin manipulation at low energies e.g. for precision beam-polarimetry and for attaining out of plane polarization has led to a study for the introduction of a Wien-filter-system. The Wien filter is used at the injection energy of MAMI which is 100 keV. Operation of this very compact system with a quadrupole compensation has been demonstrated in a test stand. Promising results have been achieved for spin rotation angles as large as 60 degrees. Installation and operation of the filter for intermediate energy physics experiments is scheduled in the near future.

1 INTRODUCTION

Spin manipulation is needed to provide longitudinal spin orientation for medium energy physics experiments in the energy range of MAMI-C (accelerator-cascade with three microtrons RTM1-RTM3 and a Harmonic Double Sided Microtron (HDSM) as fourth stage) and - almost equally important - in the energy range below. The compact set-up of the polarized electron source at the injector of MAMI [1] offers only very limited space for the introduction of a low energy spin manipulator. Therefore, the rotation system described in [2] could not be integrated and was replaced by a tuning method based on energy variations of the accelerator. In this paper we will first describe the energy variation method and how it can be extended to the increased demands at MAMI C and for low energy experiments which were required recently. In the remainder of the article we will present the alternative concept of a compact Wien filter set-up which may provide a more effective solution.

2 SPIN TUNING DEMANDS AT MAMI

The spin tuning possibilities at MAMI are summarized in table 1.

2.1 Energy shift of RTM3

The standard method for spin manipulation is fine tuning the energy of the last microtron-stage (RTM3).
The available additional spin tuning angle $\Delta\Phi_{spin}$ from a single microtron-stage can be calculated approximately from the microtron conditions and the BMT-formula [3] to be:

$$\Delta\Phi_{spin} = 2\pi a \frac{\Delta E}{E} N(\gamma_o + \frac{1}{2}(N+1)\Delta\gamma_{turn}) \qquad (1)$$

Where a is the anomalous magnetic moment of the electron (approximately 1/800), $\Delta E/E$ is the relative energy variation, and N the number of turns used in the stage. The injection energy is given by the relativistic parameter γ_0 and the energy gain per turn by $\Delta\gamma_{turn}$. For the third microtron stage (RTM3) at MAMI an energy variation of about $\Delta E/E = \pm 1.4*10^{-3}$ is feasible. This leads to a spin angle variation of about ±60 degrees. This value is limited by the available r.f.-power in the vernier section between RTM2 and RTM3. In the past this tuning range has proved to be sufficient to provide all three experimental halls with longitudinally polarized beam around the standard energy of 855MeV. The additional tuning effort caused by the energy shift is moderate, only a few hours are needed to set-up for a new tuning angle.

2.2 Energy variation method for the HDSM

It is desired to achieve longitudinal spin orientation in all experimental halls for all possible extraction energies of the HDSM (850-1500 MeV in steps of about 15MeV). It is not planned to use energy variation of the HDSM, instead the established energy variation method of RTM-3 will be improved (by larger r.f.-power in the vernier section) to provide 90 degree variation. As an additional difficulty the HDSM produces a counteracting effect because the sense of beam revolution in the HDSM is the opposite with respect to RTM-3. Because of a similar product of energy gain and number of turns this effect would almost compensate the angular shift caused by RTM-3. As a consequence, it is necessary to install another vernier section between RTM-3 and the HDSM which will compensate the energy change caused by RTM-3 tuning for spin rotation. This effort is non-negligible, but acceptable.

2.3 Low energy demands

Some experiments [4] require longitudinally polarized beam at energies below 300 MeV. Because of the dependence of equation (1) on the number of turns energy variation is not effective at these energies. However, the energy variation of the whole RTM-cascade provides additional tuning possibilities. An energy shift of more than 3% has been demonstrated. The overall spin angle variation at 180 MeV (RTM-2 output) caused by such an energy shift is already 120 degree and therefore allows in principle to provide longitudinal orientation for all possible extractions from RTM-3 (180-850 MeV in 15 MeV steps). This method is tedious because of the large tuning effort.

Table 1. Spin rotation possibilities by energy shifts

Location	Energy	Tuning/comment
Source	0.1 MeV	No
Linac	3.5 MeV	No
RTM 1	14 MeV	No
RTM 2	180 MeV	+/-120 (overall-shift)
RTM 3	855 MeV	+/-60° (standard) +/-90 (future)
HDSM	0.8-1.5 GeV	+/-90° (new r.f.-section needed)

3 THE WIEN FILTER OPTION

Spin manipulation by energy variation at even lower energies (e.g. < 14 MeV) is not effective. However, the option to do so is desirable because Mott-scattering, which is the standard method for measurement of electron polarization at low energies, requires transversal polarization. (The polarized electron source provides longitudinally polarized electrons.) It has been shown that precision polarimetry with an accuracy of about 1% is possible at an energy of e.g. 3.5 MeV which is the output energy of the injector Linac [5].

Other limitations of the energy shift method are the restriction to manipulations of the spin in the accelerator plane and the relatively long time interval for a shift of 90 degree. Obviously, a low energy spin rotator would overcome these limitations and could have the potential to avoid the inconveniences of the energy shift method (e.g. investment for r.f.-section +klystron).

3.1 Operating principle of the Wien-filter and additional requirements.

The Wien filter spin-rotator consists of crossed transverse homogenous electric and magnetic fields which fulfill the force-equilibrium condition $E/B=v$. Therefore, there is no deflection of the beam on the central trajectory through the filter. The spin rotation angle is given by

$$\theta = (eL / mc^2\gamma^2 \beta)*B \qquad (2)$$

For 100keV kinetic energy at the injection (γ=1.2 β=0.55) a 90 degree rotation can be achieved in a magnetic field of 50 Gauss with a filter length of about 0.3m. The value of the electric field is then fixed by the equilibrium condition to about 1.2 MV/m.

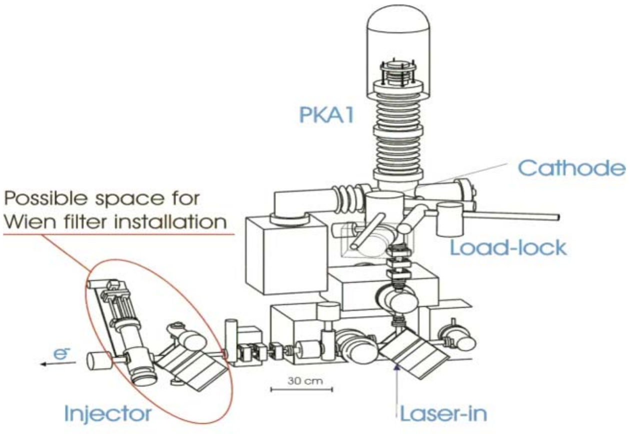

Figure 1. Polarized Electron Source.

The main requirements for the operation at MAMI are:

- Installation in the available space of approx. 90 cm.
- The operation at different rotation angles must not change the emittance parameters at the injection point.
- Tuning of the filter should be as simple as possible.
- The stability of the injection beam line must not be changed by the additional elements.

Unfortunately, the Wien filter does not provide constant focussing properties for different spin rotation angles.

Whereas the (ideal) Wien filter acts as drift space in the vertical plane, the horizontal matrix is similar to a quadrupole with a focussing force that varies between 0 m^{-1} (0 degrees) and 4 m^{-1} (for our filter) at 90 degrees. This variation has to be compensated by additional quadrupoles which are indicated in figure 2.

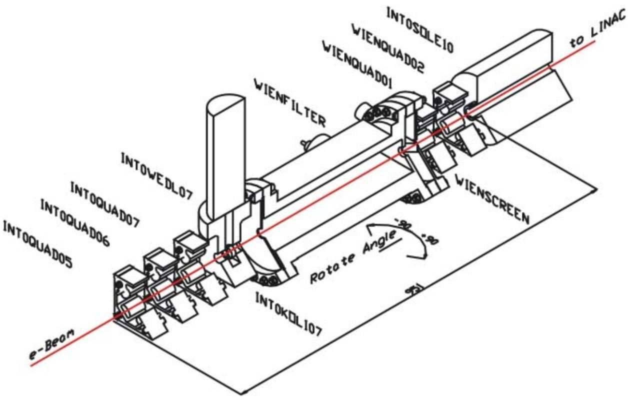

Figure 2.Proposed Installation at PKA1 1.

4 WIEN FILTER TEST BENCH: RESULTS

In order not to interfere with the ongoing operation of MAMI it was decided to install a test experiment at an external 100keV polarized electron source. It is equipped with wire scanners which allow to measure the beam emittance before and after the Wien filter. In addition, a Mott polarimeter was used to investigate the amount of spin rotation achieved for each filter setting.

4.1 Basic operation parameters

The filter was tested at electrical fields of up to 1.5MV/m (30kV total voltage over 2cm gap). This field corresponds to a spin rotation of more than 110 degrees. The amount of spin rotation was measured by a Mott polarimeter, the dependence of the precession angle on the magnetic field was as expected.

4.2 Sensitivity to beam adjustment

Beam distortions have been observed which lead to an increase of emittance for fields larger than 0.5 MV/m and misalignments of the beam exceeding 1mm. The beam adjustment accuracy imposed by this observation can be achieved. An additional view-screen at the exit of the filter will allow easy alignment in future operation.

4.3 Determination of filter matrix elements

Matrix elements of the real Wien filter for different spin rotation angles were determined by measuring the emittance before and behind the filter and then determining the transformation matrix. As next step focussing forces were calculated for the lenses of the compensation triplets. Figure 3 shows the solutions found which allow to compensate the effect of the operation of the filter. For comparison the same calculation was done for the effects of an ideal filter.

4.4 Demonstration of the compensation.

We have observed only moderate variations of emittance parameters for tuning angles up to 60 degrees. We expect even better behavior for the set-up at MAMI because the polarized source at MAMI has a smaller emittance than the test-bench source. (The test-bench requires a 10m long beam transport system at 100kV which leads to instabilities of beam adjustment and to emittance growth, whereas the line is only 1.5m long at the MAMI-injector).

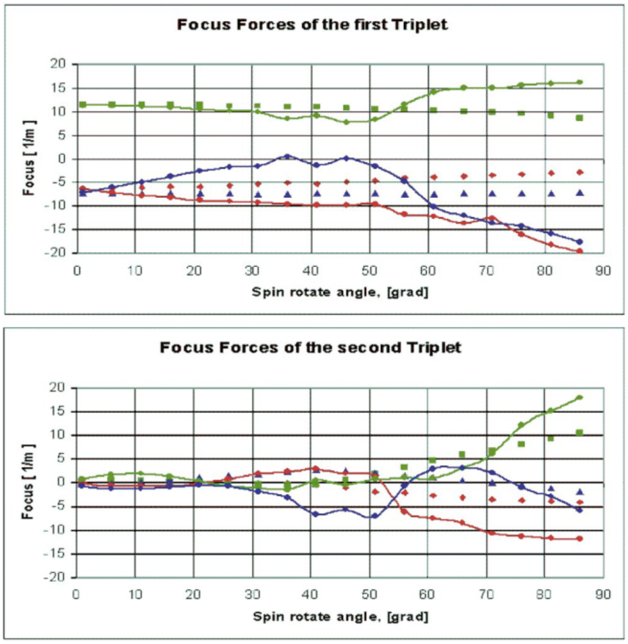

Figure 3. Focussing forces of compensating quadrupoles for ideal (points) and real Wien filter (lines).

5 CONCLUSION

Spin rotation at MAMI-C will become more flexible in future. We have explored two alternatives: An improvement of the well established method of energy variation will be technically feasible. The other method – the integration of a low energy spin rotator in form of a Wien filter – promises a higher flexibility at reduced investment. Test experiments have demonstrated an acceptable compensation of the varying focussing of the filter for spin rotation angles below 70 degrees. Therefore the integration of the Wien filter into the injector is scheduled for the end of this year.

6 ACKNOWLEDGMENTS

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