COSY Beam Time Request

For Lab. use

Exp. No.:	Session No.
E 005.2	**5**

Collaboration: JEDI

Waveguide RF Wien Filter: Commissioning and initial investigations

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Total number of particles and type of beam (p, d, polarization)	Kinetic energy (MeV)	Intensity or internal reaction rate (particles per second) minimum needed	Intensity or internal reaction rate (particles per second) maximum useful
polarized deuterons	**~970 MeV/c**	**stored ~10^9**	**stored ~10^{10}**
Experimental area	Safety aspects (if any)	Earliest date of installation	Total beam time (No. of shifts)
WASA detector, RF Wien filter in PAX section, and electron cooler	**none**	**April 15, 2017**	**3 x (2 weeks + 1 MD)**

Waveguide RF Wien Filter: Commissioning and initial investigations

The JEDI collaboration

November 11, 2016

Abstract

The plans for commissioning and first use of the new waveguide RF Wien filter are outlined. The device has been designed to perform a first direct measurement of the Electric Dipole Moment (EDM) of the deuteron at COSY. The RF Wien filter is based on a parallel plane waveguide, *i.e.*, a pair of conductors oriented parallel to the beam direction produces electric and magnetic fields. Thereby, the orthogonality condition $\vec{E} \times \vec{B}$ for a Wien filter is fulfilled very accurately.

All parts of the RF Wien filter have been manufactured. We have started to assemble the device and it shall become available for experiments at COSY in the second quarter of 2017. The driving circuit is presently produced by a company.

We would like to commission the RF Wien filter with a vector polarized deuteron beam at 970 MeV/c. **We ask for three times two weeks of beam time, each period preceded by one machine development (MD) week in 2017** (in total 9 weeks). During commissioning, several feedback loops have to be put into service to ensure stable performance during operation with beam.

1 The waveguide RF Wien filter

1.1 Introduction

The transverse electromagnetic (TEM) mode of a waveguide comes closest to the requirement of orthogonal electric and magnetic fields. Therefore, for the use of the RF Wien filter at frequencies of about 100 kHz to 2 MHz, a parallel-plate waveguide was chosen as the basic geometry. The axis of the waveguide points along the beam direction (z). The plates are separated along the x-direction by 10 cm, and the width of the plates extends along the y-direction, parallel to the magnetic field. This setup ensures that the main component of the electric field is in the x-direction, while the main component of the magnetic field points along the y-direction. Figure 1 shows a model of the RF Wien filter[1], recently published in Ref. [1].

We intend to start the commissioning effort of the new waveguide RF Wien filter with deuterons at $T = 235\,\text{MeV}$ for which $\beta = 0.459$. The device shall be operated at frequencies in the range from about 100 kHz to 2 MHz. This range of frequencies will later on enable us to carry out EDM measurements for deuterons and protons at COSY. The working frequencies of the RF Wien filter are given by

$$f_{\text{RF}} = f_{\text{rev}}|k + \gamma G|, k \in \mathbb{Z} \qquad (1)$$

[1]The design of the RF Wien filter has been worked out by a PhD student, Jamal Slim, from the Institute of High Frequency Technology, led by Prof. Dr.-Ing. Dirk Heberling, RWTH Aachen University.

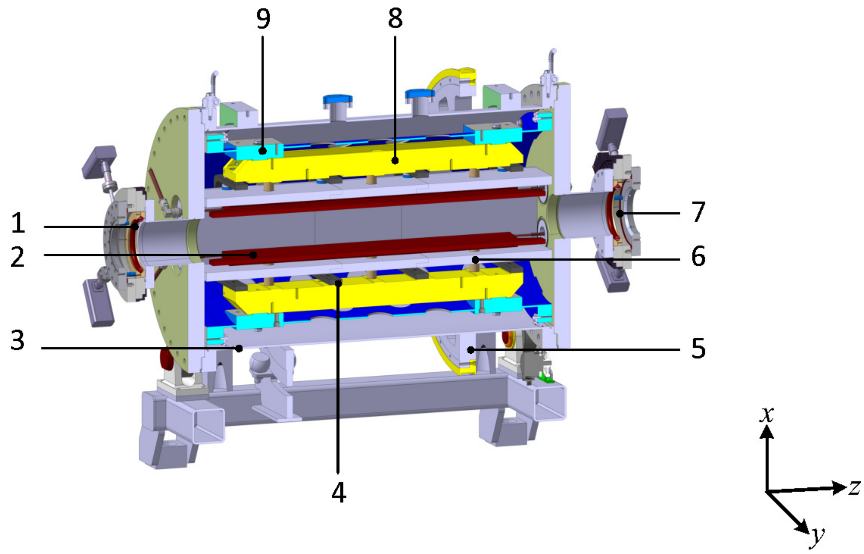

Figure 1: Design model of the RF Wien filter showing the parallel-plates waveguide and the support structure. 1: beam position monitor (BPM); 2: copper electrodes; 3: vacuum vessel; 4: clamps to hold the ferrite cage; 5: belt drive for 90° rotation, with a precision of 0.01° (0.17 mrad); 6: ferrite cage; 7: CF160 rotatable flange; 8: support structure of the electrodes; 9: inner support tube. The axis of the waveguide points along the z-direction, the plates are separated along x, and the plate width extends along y. During the EDM studies, the main field component E_x points radially outwards and H_y upwards with respect to the stored beam. (Figure taken from Ref. [1].)

where k is the harmonic number, G the gyromagnetic anomaly, γG the spin tune, and f_{rev} the revolution frequency. Table 1 summarizes the resonance frequencies for different harmonics for protons and deuterons.

1.2 Electromagnetic design

The electromagnetic full-wave simulations using CST Microwave Studio[2] were capable to model the field with an accuracy of 10^{-6}. In order to provide a zero net Lorentz force, the electric and magnetic forces must be matched at the center and the edges of the RF Wien filter. At the edges however, a special solution is required, because the rise and drop of the electric and magnetic forces are not the same, resulting in kicks on the particles passing through the device. The chosen solution aims to decompose the kicks at each side into two kicks of opposite directions in a way that they average out. To do so, the fields at the edges were decoupled, keeping the electric field unchanged while manipulating the magnetic field so that the rise and drops cross each other, as shown in Fig. 2.

The Lorentz force is given by

$$\vec{F}_{\text{L}} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) , \tag{2}$$

where q is the charge of the particle, $\vec{v} = c(0, 0, \beta)$ is the velocity vector, $\vec{E} = (E_x, E_y, E_z)$ and $\vec{B} = \mu_0(H_x, H_y, H_z)$ denote the components of the electric and magnetic fields, and μ_0 the vacuum permeability.

[2]CST - Computer Simulation Technology AG, Darmstadt, Germany, `http://www.cst.com`

	f_{rev} [kHz]	G	β	γ	γG
d	750.2	-0.143	0.459	1.126	-0.161
p	791.6	1.793	0.485	1.143	2.050

	f_{RF} [kHz]						
	$k=-4$	$k=-3$	$k=-2$	$k=-1$	$k=0$	$k=+1$	$k=+2$
d	3121.6	2371.4	**1621.2**	**871.0**	**120.8**	**629.4**	**1379.6**
p	**1543.9**	**752.2**	39.4	**831.0**	**1622.7**	2414.3	3206.0

Table 1: Operating frequencies f_{RF} (from Eq. (1)) of the waveguide RF Wien filter for deuterons (d) at a momentum of 970 MeV/c and for protons (p) at 520 MeV/c in COSY for the harmonic numbers k. The frequencies f_{RF} shown in bold fit in the frequency range from 100 kHz to 2 MHz. The revolution frequency f_{rev}, G factors, Lorentz β and γ, and the spin tune γG are given as well.

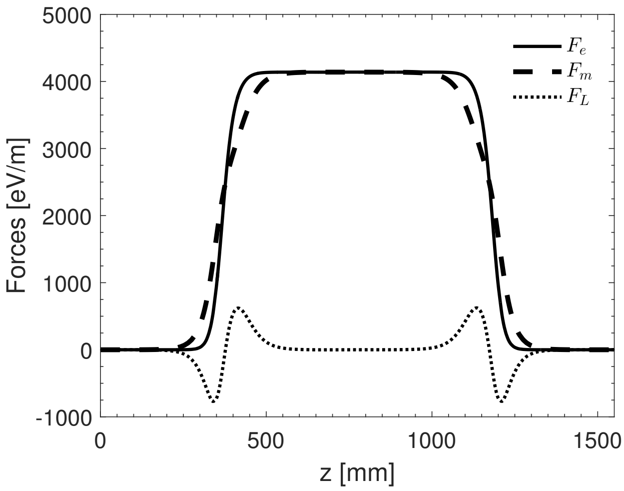

Figure 2: Electric, magnetic, and Lorentz force F_{L} as function of position along the beam direction (z coordinate). (Figure taken from Ref. [1].)

Integrating and averaging the Lorentz force $\vec{F}_{\text{L}}$, given in Eq. (2), along the axis of the RF Wien filter for the geometry shown in Fig. 1 at an input power of 1 kW, yields

$$\frac{q}{\ell}\int_{-\ell/2}^{\ell/2}\begin{pmatrix} E_x - c\beta B_y \\ E_y + c\beta B_x \\ E_z \end{pmatrix} dz = \begin{pmatrix} 5.97\times 10^{-3} \\ 7.97\times 10^{-3} \\ 1.27\times 10^{-21} \end{pmatrix} \text{eV/m}\,, \tag{3}$$

where $\ell = 1550$ mm denotes the active length of the RF Wien filter, defined as the region where the fields are non-zero.

The waveguide RF Wien filter can be rated according to its ability to manipulate the spins of the stored particles, and as a figure of merit, the field integral of $\vec{B}$ along the beam axis is evaluated, yielding for an input power of 1 kW,

$$\int_{-\ell/2}^{\ell/2}\vec{B}dz = \begin{pmatrix} 2.73\times 10^{-9} \\ 2.72\times 10^{-2} \\ 6.96\times 10^{-7} \end{pmatrix} \text{T mm}\,. \tag{4}$$

Under these conditions, the corresponding integrated electric field components are given by

$$\int_{-\ell/2}^{\ell/2} \vec{E} dz = \begin{pmatrix} 3324.577 \\ 0.018 \\ 0.006 \end{pmatrix} \text{V}\,. \tag{5}$$

1.3 Mechanical realization

The RF Wien Filter will be installed in the low-beta section of the COSY accelerator (see Fig. 3). It is equipped with an ion pump. The complete tank is rotatable up to 90° with a precision of 0.01° using a belt with a stepper motor[3] and a brake[4] to secure the position. The position of the tank is determined with a rotary encoder[5] situated on the outside of one of the big flanges. Some features of the device are described below:

- Large-angle rotations require to recable the RF Wien filter without breaking of the vacuum.
- Small angle rotations can be accomplished in-situ, *i.e.*, when the RF Wien filter is operating.
- In order to allow for the option of clock-wise and counter-clock-wise beam circulation in the machine, the same cables will be used when replacing input and output.
- Racks housing the driving circuit will be located inside the tunnel as close as possible to the RF Wien filter (*i.e.*, at the outer wall of COSY).
- Remote control of all relevant parameters takes place from a Labview control system located in the COSY control room.

All mechanical parts of the waveguide RF Wien filter have been manufactured, and the assembly of the device has started at ZEA in Jülich.

1.4 Driving circuit

The layout of the driving circuit for the waveguide RF Wien filter has been finished, and an external company[6] has been involved for its realization. We anticipate the driving circuit to be available for tests in the laboratory in early 2017.

The original circuit diagram (shown in Fig. 3 of Ref. [1] has been modified, since it is difficult to realize (or buy) a high-power variable inductance. Instead two variable capacitors are inserted in the circuit. The power splitters are replaced by four amplifiers each connected to the feedthroughs individually. The $1:0.5$ transformer is also removed. Eight -30 dB directional couplers are installed between the amplifiers and the feedthroughs to monitor the magnitudes and the corresponding phases of the current and voltages going in and out the RF Wien filter. The new modified circuit is shown in Fig. 4.

[3] Nanotec ST5918 Stepper Motor
[4] Nanotec BKE
[5] Haidenhain ROQ 437
[6] Barthel HF-Technik GmbH `http://www.barthel-hf.de/`

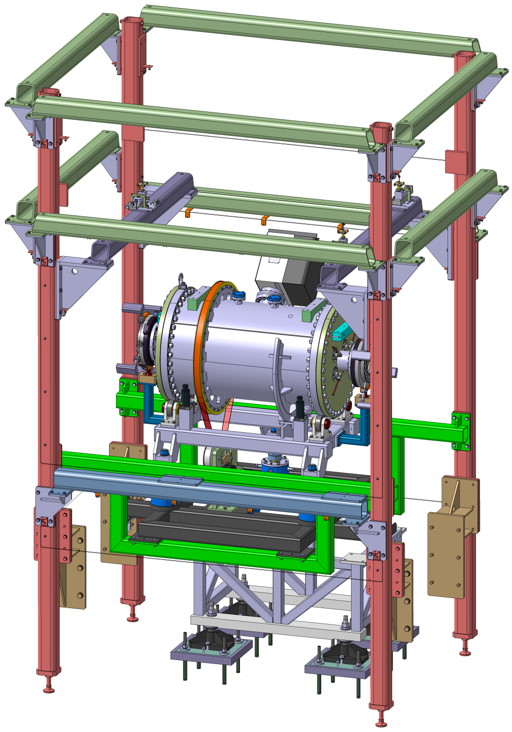

Figure 3: CAD drawing of the RF Wien filter mounted at the PAX experimental area in COSY.

2 Feedback loops

To ensure stable operation of the RF Wien filter, in total four feedback are required, depicted in Fig. 5, and briefly described below:

Loop 1 Maintains phase-lock between the spin-frequency measured with the polarimeter and the RF of the Wien filter by adjusting the frequency f_{RF} of the RF Wien filter.

Loop 2 Minimizes the Lorentz force F_{L} through a measurement with a BPM in COSY and automatic adjustment of the variable elements in the driving circuit (see Fig. 4).

Loop 3 An internal feedback system stabilizes the phase between E and B inside the RF Wien filter circuit using the elements C_{p1} and C_{p2} (see Fig. 4).

- -30 dB couplers (see Fig. 4) are used to couple the power to $50\,\Omega$. At this point current, voltage, and the phase shift between electric and magnetic field is measured. Similar elements will be inserted at every of the eight inputs and outputs to the RF Wien filter.

Loop 4 This loop keeps the beam centered on the axis of the RF Wien Filter. The signals from the Rogowski coils at the entrance and exit of the device are used to actively adjust two 4-steerer bumps, one for the horizontal and one for the vertical direction. The readout system is depicted in Fig. 7.

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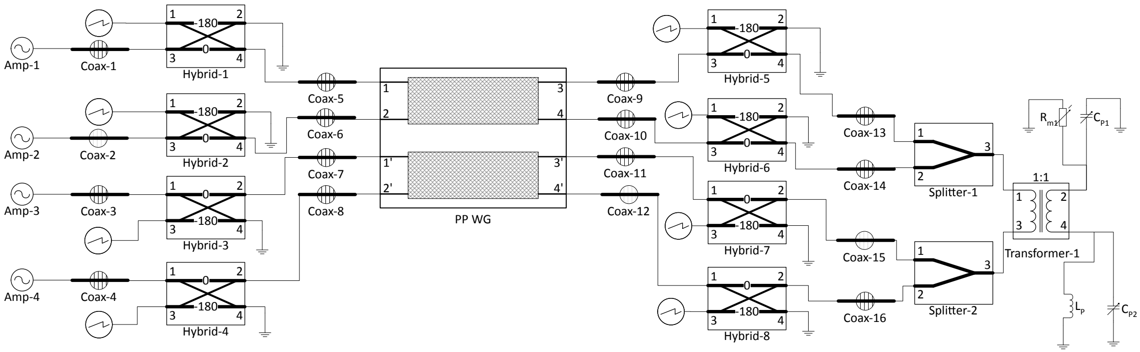

Figure 4: Modified driving circuit for the RF Wien filter. The variable resistor R_m is used to minimize the Lorentz force. (The variable R_m will be realized though a fixed resistor R and variable capacitances.) Instead of using a variable inductance L_m, as shown in Fig. 3 of Ref. [1], a fixed inductance L_p is used, and two variable capacities C_{p1} and C_{p2} are implemented in the circuit.

It should be noted that the feedback Loops 2 and 3 are actually coupled. The magnitude of the field quotient is not only related to the adjustable element R_m but also to C_{p1} and C_{p2}, and R_m also alters the phase. R_m, L_p, C_{p1} and C_{p2} altogether form the load impedance. In turn, all three variable elements R_m, C_{p1} and C_{p2} together are used to minimize the Lorentz force.

2.1 Spin tune feedback

The spin-tune feedback (Loop 1) serves two purposes: *i)* it ensures that the RF Wien filter is operating on the spin-tune resonance frequency and *ii)* maintains the relative phase ϕ between the spin direction and the oscillation frequency of the RF Wien filter. This is achieved by monitoring deuteron-carbon scattering events, the COSY RF and the Wien filter RF continously by one long-range TDC with a single time reference.

Figure 6 shows the relative phase as function of time in the cycle as it was measured during the beamtime in November 2015 (using the COSY RF solenoid). Starting at a certain time, the phase is first adjusted to a given value (here $\pi/5$) and then maintained at that value. The precision of a single measurement is determined mainly by statistics, which depends on the detector acceptance and the luminosity which one can utilize without loosing the beam too quickly. Using a dedicated detector and a 1000 s cycle we aim at $\Delta\phi \approx 100$ mrad within $2 \ldots 5$ s. As the polarisation build-up depends on the cosine of the relative phase and $\cos\phi > 0.8$ corresponds to $\phi < 37^\circ$ (640 mrad) this seems to be a reasonable goal.

In the November 2015 beam time we were controling the COSY RF to lock the phase

$$\phi = 2\pi f_{\mathrm{sol}} T - 2\pi \nu_s f_{\mathrm{rev}} T \,. \tag{6}$$

As the detector is located at a fixed position $T = n/f_{\mathrm{cosy}}$, Eq. 6 can be rewritten into

$$\phi = 2\pi n \frac{f_{\mathrm{sol}}}{f_{\mathrm{rev}}} - 2\pi \nu_s n \,, \tag{7}$$

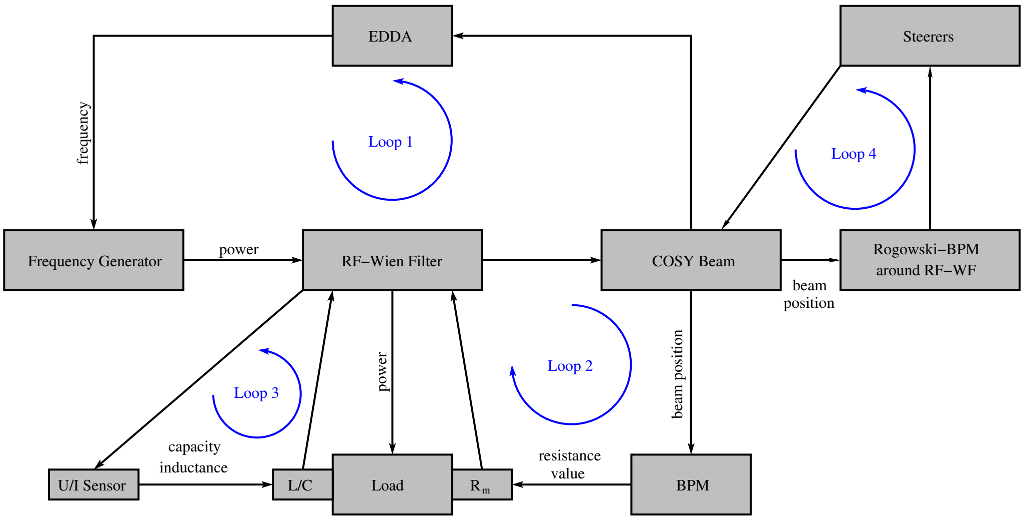

Figure 5: The three feedback loops for the operation of the RF Wien filter. **Loop 1** takes care of phase-locking the spin precession in COSY to the RF of the Wien filter. **Loop 2** minimizes the Lorentz force excerted on the beam during operation. **Loop 3** is an internal loop in the circuit of the RF Wien filter to make sure that the phase between E and B is constant. **Loop 4** makes sure the beam passes on the central axis through the Wien filter.

and thus

$$\frac{\delta\phi}{\delta f_{\text{rev}}} = 2\pi n \left(-\frac{f_{\text{sol}}}{f_{\text{rev}}^2} - \frac{\delta\nu_s}{\delta f_{\text{rev}}} \right) . \tag{8}$$

The latter term can be calculated using

$$\frac{\Delta\nu_s}{\nu_s} = \frac{\Delta\gamma}{\gamma} = \beta^2 \frac{\Delta p}{p} = \frac{\beta^2}{\eta} \frac{\Delta f}{f} \tag{9}$$

With $f_{\text{rev}} \approx 750\,\text{kHz}$ and $f_{\text{sol}} \approx 871\,\text{kHz}$ one obtains

$$\begin{aligned} |\Delta\phi| &= 2\pi n \left(1.55 \cdot 10^{-6} + 0.076 \cdot 10^{-6}\right) \Delta f_{\text{rev}} , \\ \frac{|\Delta\phi|}{\Delta T} &= \left(7.3 \frac{\text{rad}}{\text{Hz s}} + 0.36 \frac{\text{rad}}{\text{Hz s}}\right) \Delta f_{\text{rev}} , \\ &\approx 7.7 \frac{\text{rad}}{\text{Hz s}} \Delta f_{\text{rev}} . \end{aligned} \tag{10}$$

With a stepping of 3.7 mHz (given by the capabilities of the COSY RF system) we could induce an adjustment in steps of $\Delta\phi \approx \pm 30\,\text{mrad/s}$, *i.e.*, the precision of the measurement was in the same order (or even better in case several points were combined for long term behaviour) as the minimum induced change, which led to the problem, that in most cases the question was whether to apply a change or not instead of applying a smooth change.

During the precursor experiment, we will instead directly control the frequency of the RF Wien filter, thus

$$\phi = 2\pi f_{\text{RF}} T - 2\pi \nu_s f_{\text{rev}} T . \tag{11}$$

As a change in f_{RF} does not imply a change in the spin tune ν_s nor in time T the beam is passing the detector, we simply have

$$\Delta\phi = 2\pi T \Delta f_{\text{RF}} , \tag{12}$$

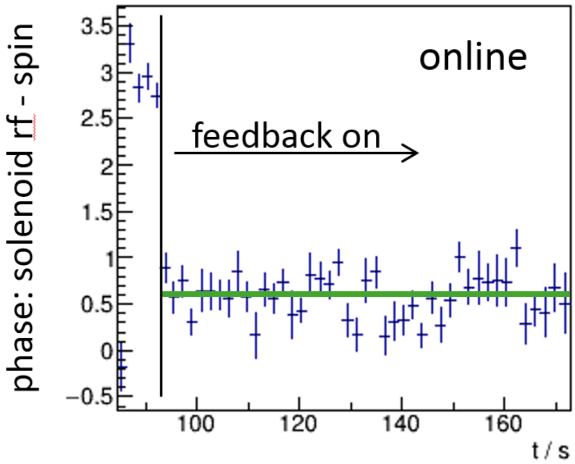

Figure 6: Relative phase between the spin precession and the solenoid RF as function of time. The feedback system had been switched on at $t \approx 90\,\mathrm{s}$. First, an initial phase jump to $\phi = \pi/5$ was performed, then the phase has been maintained at that value.

and

$$\frac{|\Delta\phi|}{\Delta T} = 6.3\,[\mathrm{rad\,Hz^{-1}\,s^{-1}}]\Delta f_{\mathrm{RF}}\,. \tag{13}$$

This is similar to the situation in the November 2015 experiment. Thus, we aim at a stepping of not more than $1\,\mathrm{m\,Hz}$ of the RF Wien filter frequency f_{RF}, and in addition, f_{RF} also has to be stable within that range over a period of several seconds. Thus for the precursor experiments, an RF signal generator covering the frequency range of about $0.1\,\mathrm{MHz}$ to $2\,\mathrm{MHz}$ has been ordered[7].

2.2 Lorentz force feedback

This feedback loop is required in order to ensure a minimal Lorentz force during operation. The Lorentz force is given by Eq. 2, where q is the charge of the particle, $\vec{v} = c(0, 0, \beta)$ is the velocity vector, $\vec{E} = (E_x, E_y, E_z)$ and $\vec{B} = \mu_0(H_x, H_y, H_z)$ denote the components of the electric and magnetic fields, and μ_0 the vacuum permeability. For a vanishing Lorentz force $\vec{F}_{\mathrm{L}} = 0$, the required field quotient Z_q is determined, which yields

$$\begin{aligned} E_x &= -c \cdot \beta \cdot \mu_0 \cdot H_y\,, \\ Z_q &= -\frac{E_x}{H_y} = c \cdot \beta \cdot \mu_0 \approx 173\ \Omega\,. \end{aligned} \tag{14}$$

A non-vanishing Lorentz force, generated for example by a slight change of the Lorentz β of the beam, leads to an excitation of the beam at the frequency f_{RF} of the RF Wien filter. This excitation will be detected using a suitable BPM in COSY. This signal will then be used to adjust the variable elements in the driving circuit (see Fig. 4) to minimize the Lorentz force during operation with beam.

[7] Rohde & Schwartz, Signal Generator SMB100A

2.3 Internal $\vec{E} \times \vec{B}$ feedback

The orthogonality of $\vec{E}$ and $\vec{B}$ in the RF Wien filter is ensured by measuring voltages, currents, and the phase between them in the driving circuit (shown in Fig. 4) and by actively adjusting the variable elements in the driving circuit to make sure that voltage and current are in phase.

2.4 Beam position feedback

For controlling the beam position during spin manipulation measurements with the RF Wien filter, two Rogowski coils are used to measure the beam position at the entrance and exit of the RF Wien filter (see Fig. 1, label 1). A schematic diagram for the readout scheme of one Rogowski coil is shown in Fig. 7. Each Rogowski coil is divided into four segments. The bunched beam passes the Rogowski coil and induces a voltage in each segment. Each coil segment is connected to a pre-amplifier to increase the induced signal. For the read out of the induced voltages, two lock-in amplifiers[8] are used. The lock-in amplifiers are locked to the COSY-RF (after conversion to a TTL-signal). A measurement with the synchronised lock-in amplifiers is performed, when a BPM trigger signal is sent.

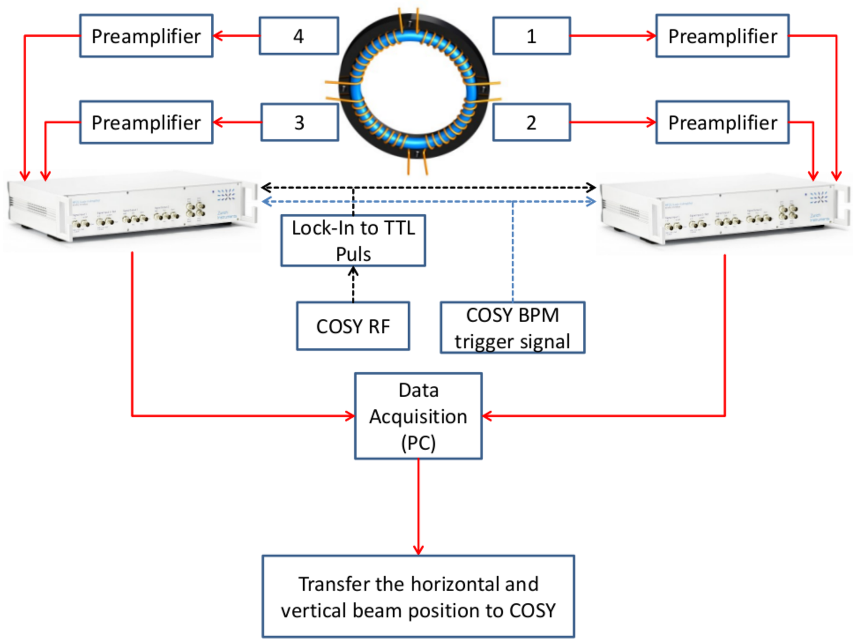

Figure 7: Schematic readout diagram for Rogowski coil beam position determination.

The sampling rate of the lock-in amplifier is around 450 MS/s. The data acquisition is performed with a PC. The raw data measurement time is adjustable and sent via Ethernet. Also the averaged horizontal and vertical beam position is sent via Ethernet.

The COSY BPM control system is presently being upgraded involving an external company[9]. Thereby, active control of the beam orbit in COSY during the cycle will become available in early 2017. Maintaining the beam position at the entrance and exit

[8] Zurich Instruments, HF2LI lock-in amplifier `https://www.zhinst.com/`

[9] COSYLAB `http://www.cosylab.com/`

of the RF Wien filter (**loop 4**) will be facilitated by a feedback loop implemented inside the upgraded COSYLAB system.

2.5 Interplay of the feedback loops

As the feedback **loop 1** acts on the Wien filter frequency there is no direct impact on beam dynamics. However, one has to assure that there is also no indirect impact by the other feedback loops, *e.g.*, by a mismatch of the E and B fields, as a results of a feedback change resulting in an orbit correction. This has to be studied for small frequency changes as well as larger changes (up to 1 Hz) for limited times (up to 1 s). At the beginning of a measurement cycle, there has to be a *phase jump* moving the relative phase to the reference value. The impact of the orbit control **loop 4** on the spin tune has to be investigated as well.

3 Commissioning of the waveguide RF Wien filter

3.1 Results of measurements with the prototype RF Wien filter

In 2014, a prototype RF E×B Wien filter using separate systems for the generation of electric and magnetic fields has been successfully commissioned and utilized during two weeks of beam time. As a result of these investigations, it was shown that the prototype can be operated in a Wien-Filter configuration at harmonic $k = -1$ (at a frequency of 871.0 kHz, see Table 1) to flip the vertical polarization of a 970 MeV/c deuteron beam without exciting coherent beam oscillations. Tuning of the device to minimize the transverse Lorentz force was accomplished by operating the machine near a betatron resonance. It was possible to show that the device effectively operates like an RF solenoid. Further details about these investigations can be found in Ref. [2]. During 2015, measurements with the prototype RF Wien filter at harmonic $k = +1$ (at a frequency of 629.4 kHz) were carried out equally successful, and with these measurements, without modifications and special tuning the frequency range of the prototype RF Wien filter was exhausted.

3.2 First tests with the waveguide RF Wien filter

The waveguide RF Wien filter will be installed at the PAX interaction point at COSY. Proper alignment of the beam position in the device will be accomplished by a pair of Rogowski coils at the entrance and exit of the vessel that serve as BPMs [3] (see label 1 in Fig. 1). The β-functions at the PAX interaction point can be adjusted in the range between about $\beta = 0.4$ to 4 m, whereby the beam size can be changed accordingly. With respect to the commissioning of the waveguide RF Wien filter, we would like to repeat the procedures during the commissioning of the prototype using the different harmonics available, in order to show that the device is functioning as expected.

The waveguide RF Wien filter can be rotated in short time in-situ by more than 90° about the beam axis without breaking the vacuum with an angular precision of 0.01° (0.175 mrad) using a belt drive (see label 5 in Fig. 1). Once the spin manipulation behavior of the system is determined, the waveguide RF Wien filter can be rotated by 90° around the beam axis. In this configuration, the RF E×B dipole in Wien filter mode will no longer directly act on the particles' MDM, but still modulate their spin tune γG. In conjunction with the imperfection fields distributed along the accelerator ring, an RF

Wien filter with radial electric fields can lead to an EDM induced build-up of a vertical polarization component. It is foreseen to use the new waveguide RF Wien filter for systematic investigations of sources for false EDM signals. To this end, extensive studies about the polarization buildup using an RF Wien filter to detect the EDM signal were carried out by JEDI. These are described in Ref. [4], where it is shown that in particular quadrupole misalignments mimic the buildup of polarization due to an EDM (see Figs. 4 and 5 of Ref. [4]).

As explained above, the commissioning of the prototype RF Wien filter took about one week for each of the employed harmonics ($k = -1$ and $+1$, see Table 1). It proved time comsuming to set up the machine near a betatron resonance, because in order to gain a high sensitivity to the induced beam oscillations, the accelerators optics needed to be modified so that a vertical betatron sideband is shifted exactly to the RF E×B frequency at 871 kHz (see Fig. 5 of Ref [2]). In this reference, details about the measurement procedure are described as well. Once the machine is setup near the betatron resonance, testing the performance of the waveguide RF Wien filter at the $K = -1$ harmonic should be achievable within the proposed two weeks of beam time in the 2$^{\text{nd}}$ Quarter of 2017.

4 Request for beam time for 2017

We request **three times two weeks of beam time, plus one MD week preceding each of the three beam time periods** in 2017. The three beam time periods shall be used to accomplish the items described in the following:

1. 2$^{\text{nd}}$ **Quarter 2017:** (2 weeks + 1 MD)

   - During the laboratory tests, the internal **feedback loop 3** will be implemented. Subsequently, we will install the RF Wien filter in the PAX section at COSY and operate it with a radial B field, *i.e.*, rotated by 90° with respect to EDM measurement mode.
   - During commissioning, the RF Wien filter will be operated at the $K = -1$ harmonic at $f_{\text{RF}} = 871$ kHz.
   - The beam position feedback **loop 4** based on COSYLAB will be implemented to maintain a stable beam position at the entrance and exit of the RF Wien filter.
   - Measurements near the betatron resonance will be carried out to show that the RF Wien filter operates as a spin rotator.

2. 3$^{\text{rd}}$ **Quarter 2017:** (2 weeks + 1 MD)

   - Implementation of the **spin tune feedback loop 1** using the WASA detector.
   - Implementation of the **Lorentz force feedback loop 2**.
   - Study the influence of the betatron amplitude at the RF Wien filter on the Lorentz force.

3. 4$^{\text{th}}$ **Quarter 2017:** (2 weeks + 1 MD)

   - Accomplish test of complete system with all four feedback loops active.
   - First EDM measurements at the two harmonics $K = \pm 1$ at frequencies $f_{\text{RF}} =$ 871 and 621 kHz. Other frequencies will be made available later.

References

[1] J. Slim *et al.*, Nucl. Instrum. Meth. A **828** (2016) 116.

[2] S. Mey and R. Gebel, *Towards an RF Wien filter for EDM Experiments at COSY*, Proceedings of the International Beam Instrumentation Conference, Proceedings of IPAC 2015, May 3 - 8, 2015, Richmond, VA, USA, available from `http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/thpf031.pdf`.

[3] F. Hinder, H. J. Krause, H. Soltner and F. Trinkel, *Development of new beam position monitors at COSY*, Proceedings of the International Beam Instrumentation Conference, IBIC2015, Melbourne, Australia, available from `http://ibic2015.vrws.de/papers/tupb015.pdf`.

[4] M. Rosenthal and A. Lehrach, *Spin tracking simulations towards electric dipole measurements at COSY*, Proceedings of the International Beam Instrumentation Conference, Proceedings of IPAC 2015, May 3 - 8, 2015, Richmond, VA, USA, , available from `http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/thpf032.pdf`.