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RESONANT SPIN DEPOLARIZATION AT THE TEST FACILITY KARA: OVERVIEW OF RECENT EFFORTS

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Abstract

The Karlsruhe research accelerator KARA offers a setup to measure the beam energy with resonant spin depolarization. The depolarization is excited by the stripline kickers of the bunch-by-bunch feedback system and the resonant frequency is measured via change in Touschek lifetime. Energy measurements with resonant spin depolarization are implemented as a standard routine in the control system and are used regularly to measure both the beam energy and the momentum compaction factor for different energies and optics regimes.

Long-time experience with the setup, short polarization time, and variation options of beam energy in combination with much available beam time qualify KARA as a test facility for systematic studies. Such studies are of particular interest for future colliders designed for precision studies like FCC-ee, as resonant spin depolarization is known for its high accuracy. This contribution presents the resonant spin depolarization setup at KARA and selected results of recent measurement campaigns.

BASIC PRINCIPLE

Measuring the beam energy in a circular accelerator is a non-trivial task, while at the same time of critical importance for precision experiments such as the proposed FCC-ee [1]. One approach is the measurement of the resonant depolarization (RDP). An asymmetry in the spin-flip probability due to the emission of synchrotron radiation leads to the buildup of transverse polarisation in electron storage rings [2]. Exciting the beam with the corresponding resonant frequency will lead to a depolarization. This resonant depolarization leads to a change in Touschek lifetime, which can be picked up by a beam loss monitor. With the knowledge of the excitation frequency, which led to the depolarization, the beam energy can be determined with a high precision [3].

KARLSRUHE RESEARCH ACCELERATOR

The Karlsruhe Research Accelerator (KARA) [4, 5] is an electron storage ring and synchrotron light source in operation for more than 20 years. Before 2016 it was known as Angstromquelle Karlsruhe (ANKA), whereas the focus now is on providing a test facility for accelerator R&D. The basic parameters of KARA are listed in Tab. 1. A discussion of measurements of the beam optics, which took place in parallel to RDP measurements, can be found in a companion paper [6].

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Table 1: KARA Parameters [4, 5]

Parameter	Value
Energy	0.5 - 2.5 GeV
Beam Current	0.1 - 200 mA
Harmonic Number	184
Circumference	110.4 m
RF	500 MHz
Tunes (horizontal / vertical)	6.77 / 2.82
Synchrotron Frequency	31 - 35 kHz

Operation

While KARA is operated at different energies, with varying beam current, filling pattern and bunch length, the default operation mode consists of: Accumulating beam current at 0.5 GeV for roughly an hour, with a filling pattern of evenly distributed bunches for 4/5 of the storage ring and a section of empty buckets. After the nominal beam current is reached, the energy is increased during a slow energy ramp of 3-4 minutes to 2.5 GeV. While providing synchrotron light to the beamlines, the beam current decays slowly to roughly half of the injected beam current over a period of 23 hours, when the next injection cycle starts.

Resonant Spin Depolarization

At 2.5 GeV, the polarisation time at KARA is about 10 minutes [7]. This provides a quick turn-around time for systematic depolarization measurements. First measurements have been carried out in 2004. Over the years, both hardware and software involved in the measurement setup have been improved to a state, where only minimal effort is required to successfully perform a resonant spin depolarization (RDP). During dedicated RDP measurements, typically only up to a fifth of the storage ring buckets are filled, which allows to increase the bunch current compared to a more even filling pattern, which improves the signal to noise ratio while measuring small changes via the bunch-current dominated Touschek effect.

HARDWARE

BBB Feedback System

The bunch-by-bunch (BBB) feedback system at KARA typically takes care to suppress coupled-bunch instabilities around the betatron frequencies [8], but it also allows us to excite the electron beam with any given frequency, which we exploit to slowly scan through a frequency range around

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the estimated spin frequency. In addition to the frequency, the feedback system also allows to select which bunch to excite and adjust the excitation amplitude.

Stripline Kicker

The output of the BBB system drives a broadband amplifier which is connected to a vertical stripline, which is shown in Fig. 1 [9]. Using the full scale output of the amplifier of 160 W and one of the two strips the estimated magnetic field of the stripline with half-plate distance of $r = 28$ mm is:

$$B_{\text{Stripline}} \approx 50\,\mu\text{T} \tag{1}$$

with an estimated kick strength for the length of the stripline of 300 mm:

$$\Phi_{\text{Kick}} \approx 1.7\,\mu\text{rad} \tag{2}$$

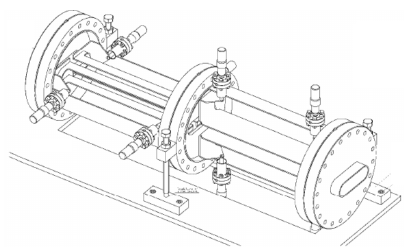

Figure 1: CAD drawing of the KARA stripline kicker [9].

Beam Loss Monitor

To measure the change in Touschek lifetime and therefore the beam losses, a Pb-glass block connected to a photomultiplier is used. A frequency counter with a configured threshold value continuously counts the event rate. At stable 2.5 GeV operation, this loss rate is rather stable and proportional to the overall beam current. A temporarily relative increase in loss rate is used to determine the resonant spin depolarisation event.

SOFTWARE

KARA uses EPICS as the general control system [10]. While modernizing the RDP setup over the years, focus was put on fully integrating each component relevant for the measurements into the control system infrastructure. On the one hand, this allows to utilize all other components of KARA during RDP measurements, while on the other hand, elements of the RDP setup can also be used outside the RDP context. The lead glass counter, for example, is now part of the overall beam loss monitoring setup of KARA.

Measurement Scripts

With the full integration into the control system, there are also multiple options in how to set up the measurement environment and scripts. For the most time we used MATLAB and the well established Matlab Middle Layer (MML) [11]. The MML serves as an interface to the control system, provides all relevant meta data of the state of the accelerator and allows to perform related measurement of beam functions, such as dispersion and chromaticity. Next to the actual measurement, the scripts also take care of automatically analysing and storing the raw and relevant meta data, as well as documenting each measurement in an electronic logbook, including a plot of the scan and analysis. This allows for a quick first look at the data and via the logbook API also a programmatic approach for further analysis.

MEASUREMENTS

An in-depth discussion of recent measurements can be found in a second companion paper [12].

Single Sweep

A single RDP measurement is defined by three parameters: the sweep duration t_s, lower f_l and upper f_u limit of the excitation frequency. t_s is for most scans between 300 and 600 seconds. The overall excitation frequency range should not exceed the synchrotron frequency: $f_u - f_l < f_s$. Otherwise there is the risk to excite a side-band of the resonant frequency, which will also lead to a depolarization of the beam. To verify that the excitation f_{dep} is not on a side-band, we vary f_s via change in RF voltage resulting in a change of Δf_s and compare the excitation frequency in a subsequent RDP scan. The excitation frequency corresponding to the beam energy will stay unchanged, while the side-band frequency will move by the same amount as Δf_s. Before the next scan can be started, a reasonable amount of time T_{wait} should pass, so that the beam can re-polarize itself. A T_{wait} we typically wait is around 20 to 30 minutes.

Analysis

The initial - automated - analysis of a RDP measurement fit a step function to the measured beam loss rate. Based on the fit parameters of the step function the depolarization frequency f_{dep} and the energy E is determined.

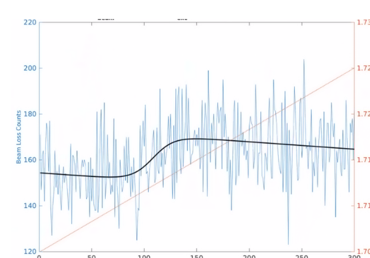

Figure 2: Example of the initial, automated analysis of a RDP measurement. The left axis shows the measured loss rate and the right axis the excitation frequency. The black curve is the automated fit of the step function, which determines the depolarization frequency f_{dep}.

Automated Scans

Considering the wait time T_{wait} and the sweep time t_s we can perform 2-3 RDP measurements per hour. As one RDP scan including the preliminary analysis is automated, we can

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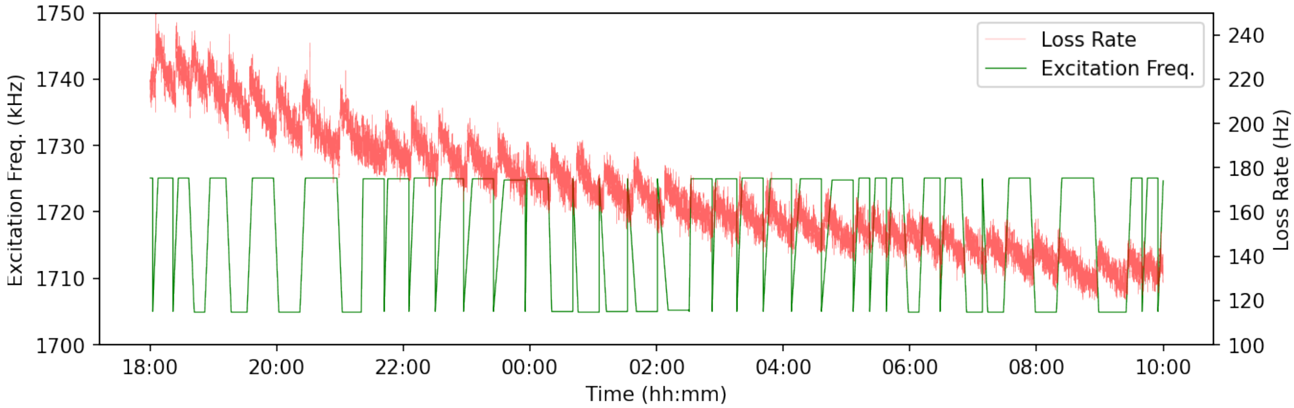

Figure 3: Example of automated measurement. The red data shows the beam loss rates with steps indicating a resonant depolarization event. The blue data shows the frequency the beam is excited with. Flat periods correspond to the wait time in between scans with no active excitation. Across the all measurements the sweep duration, wait time and direction of frequency sweep were modified. Analysis of the data can be found in [12].

set up a measurement matrix with varying RDP parameters such as sweep duration and wait time, as well as other beam parameters such as the synchrotron frequency f_s, allowing to systematically study the influence of these parameters regarding the outcome of the measurement or the change in how the depolarization occurs. Fig. 3 shows an example of a fully automated measurement campaign covering 14 hours.

OUTLOOK

Re-implementation of Measurement Routine

Recently, we started migrating more and more services to Python, levering the strong scientific eco system and easier server-side integration as well as related site-specific services [13]. The Python version of our RDP scripts is currently under evaluation, which also allows to better fine-tune the sweep and correlate the measurement with additional data.

Additional Beam Loss Monitors

Recently, 24 additional beam loss monitors (BLMs) have been installed at KARA. These BLMs use a different detector material and different readout electronics compared to the Pb-glass setup. With the new detectors additional areas of the storage ring can be covered with the potential of improving the overall statistics of the measurements.

Systematic Studies

So far, we mostly looked into sweep speeds, sweep direction and wait time between scans. Additional parameters to explore are for example studies at different beam currents and filling patterns, the influence of our insertion devices, excitation with varying excitation amplitude or partial excitation of the filling pattern.

Exploring Lower Energies

For some of the systematic studies, the ten minute polarization time might actually be too short. We are therefore currently investigating to perform RDP measurements at slightly lower energies in the range of 2 - 2.4 GeV.

CONCLUSION

Due to the polarization characteristics at KARA and the fully automated measurement routines, resonant depolarisation (RDP) can be studied systematically. This allows us to gain insight into future experiments for the FCC-ee, where performing RDP scans will be crucial.

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