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Beam instrumentation for the future ultra-low energy electrostatic storage ring at FLAIR

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Abstract To enable the efficient investigation of some fundamental questions concerning the physics with low-energy antiprotons, a novel Ultra-low energy Storage Ring (USR) will be developed. Aiming to be a multipurpose machine, it puts challenging demands on the necessary beam instrumentation and requires new diagnostic methods as most of the standard techniques will no longer work. In this paper, beam diagnostics devices proposed for the USR are presented and their further development is discussed.

Keywords Beam · Low energy storage ring · Antiprotons · Diagnostics · Instrumentation

1 Introduction

The Facility for Low-energy Antiproton and Ion Research (FLAIR) will supply users with high-luminosity low-energetic antiproton beams for nuclear physics-type experiments and atomic collision studies [1, 2]. Antiprotons will be slowed down to 20 keV by the novel electrostatic Ultra-low energy Storage Ring (USR) [3] which offers world-wide unique conditions for both in-ring studies and experiments with extracted slow beams. The USR will provide variable beam characteristics making a

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Table 1 General parameters of the USR (here only antiprotons are considered)

Energy	300 – 20 keV
Velocity	0.025 c – 0.006 c
Number of particles	$\leq 2{\cdot}10^7$
Revolution frequency	46 – 177 kHz
Bunch length	1 ns – DC beam
Effective $\bar{p}$ rates for in-ring experiments	10^{10} – 10^{12} pps
Average rates of extracted $\bar{p}$'s	$5{\cdot}10^5$ – 10^6 pps

wide range of low energy physics experiments with antiprotons (and possibly highly charged ions) feasible.

2 Beam diagnostics challenges imposed by the USR

The USR will be able to accept a 300 keV antiproton beam consisting of up to $2{\cdot}10^7$ particles. The revolution frequency f_{rev} of such a beam is equal to 177 kHz and corresponds to a revolution time $t_{rev} = 5.6\ \mu$s. As far as bunches of hundreds of nanoseconds are of the main interest, a harmonic mode h = 10, corresponding to the RF frequency $f_{RF} = 1.77$ MHz and RF buckets of about 560 ns, might be chosen. The RF field will typically be applied after the beam has reached a quasi-DC state which will lead to the generation of 10 bunches with $2{\cdot}10^6$ particles (300 fC) each. Another issue is the deceleration stage during which the beam will be slowed down to 20 keV. As the harmonic number h (and so the number of bunches) stays constant and the revolution frequency decreases to $f_{rev} = 46$ kHz ($t_{rev} = 21.8\ \mu$s) during the deceleration, the main RF frequency will have to be changed from 1.77 MHz to 458 kHz. This should be taken into account while preparing the beam instrumentation. Furthermore, both slow and fast beam extraction modes are foreseen [4]. In the case of slow extraction, the beam needs to become a quasi-DC (coasting) beam again and it should be also considered. Moreover, the beam diameter should be kept in mind as well as it may vary from a few millimetres up to 2 cm at some points of the ring. Finally, the most challenging mode of operation of the USR is a production of ultra-short (1–2 ns) bunches for in-ring experiments [5]. Initially, a 20 keV coasting beam is planned to be adiabatically captured into 50 ns stationary buckets formed by a 20 MHz cavity operating at a high harmonic mode. With $h \approx 430$ one gets only $\leq 5{\cdot}10^4$ particles (8 fC) per bunch. The final bunch length will depend on the initial RF voltage applied to capture the circulating beam. The desired ultra-short bunches of 1–2 ns duration (corresponding to a few millimetres pulse length only) will then be formed by an additional double drift buncher with a relatively low voltage. Having in mind such a large number of different beam parameters (see Table 1), it is clear that the USR will require different diagnostic techniques optimised for a wide range of measurements.

3 Beam instrumentation for the USR

Capacitive Pick-Up Due to a low number of particles and a low signal-to-noise ratio even for a 500 ns bunch mode operation of the USR, a highly sensitive resonant beam position monitor is currently under investigation. The idea is to build a capacitive

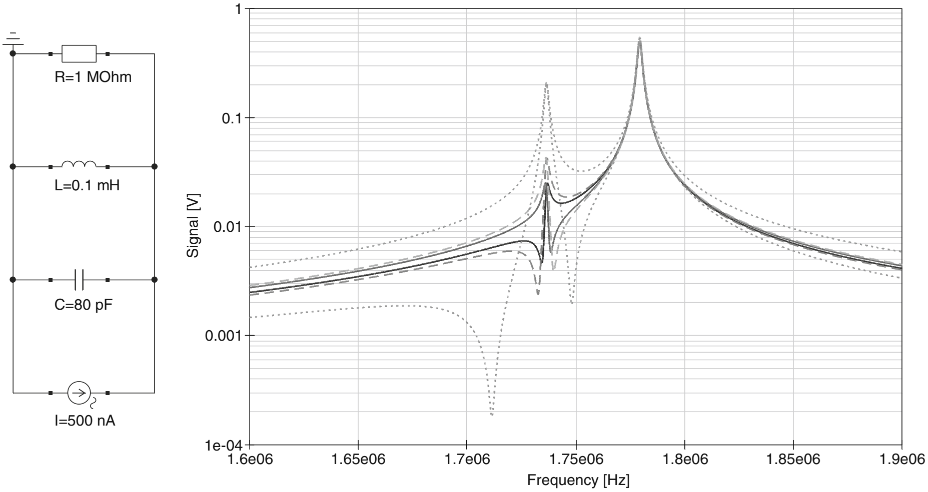

Fig. 1 A resonant PU electrode equivalent circuit (*left*) and resulting spectra for different beam displacements (*solid line*: ± 1 mm, *dashed line*: ± 2 mm, *dotted line*: ± 10 mm) for two electrodes coupled with a parasitic capacitance (*right*)

pick-up (PU) as a part of a resonant circuit (see Fig. 1, left) well tuned to a bunch repetition frequency and to benefit from a large gain at a specific frequency only. Different PU geometries have been examined and a great improvement of sensitivity to the beam displacement has been achieved by separating the PU electrodes with a ring on a ground potential. However, preliminary studies of equivalent circuits showed that a coupling (parasitic) capacitance between two separate electrodes cannot be neglected as it results in a loss of information on beam position. Even for a small value of a coupling capacitance (a few pF) not only is a difference signal smaller by three orders of magnitude as compared to uncoupled electrodes, but also the frequency spectrum is distorted (Fig. 1, right). The problem can be resolved by creating just one resonant circuit directly measuring the difference signal from two electrodes. Nevertheless, further optimisation studies are required to overcome these difficulties.

Profile Monitor In order to measure the beam size, several beam profile monitors are presently under consideration. A scrapers-based method could be one of the options, but it was reported to be very slow and it is not unusual to spend several hours on its proper tuning [6]. A simple phosphor screen-based device would deliver sufficient information on the beam profile, but it has been shown that ion sputtering damages the screen surface [7]. This issue is planned to be investigated in the near future. An interesting alternative might be a secondary electron emission foil-based monitor. In addition, two other solutions proposed at CERN AD will be considered. One of them makes use of a Gas Electron Multiplier (GEM) [8] and for the other one a microwire chamber consisting of 5–10 μm diameter wires has been developed [9]. The most suitable monitor will be chosen and optimised for the USR. The listed devices can be successfully used for the observation of injected and extracted beams, but the destructive character of measurements makes them useless for the in-ring monitoring of a circulating beam. A much less perturbing supersonic gas jet curtain monitor, which is currently under development in the QUASAR Group [10], may overcome difficulties with the non-destructive profile measurements in the ring.

Faraday Cup Although a Faraday cup is a fully destructive monitor, it is a reliable device for absolute beam current measurements in transfer lines or during the first turn of the beam. However, the average currents of delivered beams in the USR case would require a sensitive solution for fA–pA measurements. The idea to overcome this problem is to take the advantage of the bunched beam delivery and to measure the peak current with a fast current-to-voltage converter working in the required bandwidth.

Schottky Pick-Up A set of longitudinal Schottky pick-ups, like those proposed for CERN AD and ELENA [11], is considered to be used as a non-destructive system for intensity, momentum spread and mean momentum measurements by FFT-based spectral analysis of Schottky signals.

Cryogenic Current Comparator An interesting option is a SQUID-based cryogenic current comparator (CCC) for absolute, non-destructive in-ring measurements of nA beam currents. A similar system demonstrated its promising capabilities at GSI [12]. However, further optimisation (in terms of shielding, cooling, vibration isolation etc.) will be necessary as the CCC operation can easily be affected by external factors. Moreover, this device was not designed for bunched beam measurements. There is still place for improvements, e.g. a fractional turn loop sensing coil may enhance a CCC sensitivity above that of a SQUID [13], and extensive R&D is required.

4 Summary

A set of diagnostics devices, ranging from fully destructive monitors to non-perturbing ones, has been proposed for the USR. The machine puts very challenging demands on the necessary beam instrumentation and most of the standard techniques are not suitable. Ultra-short bunches (1–2 ns) on the one hand and a quasi-DC beam structure on the other, together with a variable very low beam energy (300 keV to 20 keV), ultra-low currents (down to fA–pA range for non-circulating beams) and few particles ($\leq 2{\cdot}10^7$), require the development of new diagnostic methods. The proposed solutions should overcome these problems and assure stable and reliable operation of the USR.

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