Cockcroft-11-29

ACCELERATOR R&D IN THE QUASAR GROUP

C.P. Welsch
University of Liverpool and the Cockcroft Institute, UK
on behalf of the QUASAR Group

ACCELERATOR R&D IN THE QUASAR GROUP

C.P. Welsch[#]
University of Liverpool and the Cockcroft Institute, UK
on behalf of the QUASAR Group

Abstract

Since its start in 2007, the QUASAR Group's research activities have grown considerably: Whilst the research program towards an ultra-low energy storage ring (USR) at the future facility for low-energy antiproton and ion research (FLAIR) is still the main research focus, developments of beam diagnostics tools for accelerators and lights sources, investigations into superconducting linear accelerators and medical applications, including the potential use of antiproton beams for cancer therapy purposes, widen the Group's activities and international collaboration considerably. An overview of the QUASAR Group's research achievements in accelerator science and technology to date is given in this contribution.

THE ULTRA-LOW ENERGY STORAGE RING (USR)

The Facility for Antiproton and Ion Research (FAIR) at GSI will include a dedicated facility for research with low energy antiprotons in the keV regime or even at rest, named FLAIR [1]. The electrostatic Ultra low energy Storage Ring (USR) will provide cooled beams of antiprotons in the energy range between 20-300 keV [2].

Results from Beam Dynamics Studies

In order to fulfill the requirements from the envisaged experiments on the characteristics of the stored and extracted antiproton beams, a complete re-design of the USR was necessary. The resulting split-achromat lattice had not been proposed for any electrostatic storage ring before. It allows for capturing a rather large and un-cooled antiproton beam from the low energy storage ring (LSR) at 300 keV, beam cooling and deceleration to 20 keV, features a special short bunch operation mode and incorporates slow and fast extraction. A particular challenge was the development of a lattice for the USR that allows for the generation of ultra-short pulses in the nanosecond regime, as required by in-ring atomic collision experiments. It was shown that this can either be achieved by a combined bunching/debunching scheme or multiple adiabatic splitting [3].

In addition, a combined fast and slow extraction system has been developed. It consists of a system of electrodes that generate a local orbit bump that brings the beam close to an extraction (septum) electrode. An adequately placed electrostatic sextupole is used to generate the required phase space distortion. An RF electric field is then used for so-called knock-out extraction from the ring [4]. It should be noted that the USR will be the first electrostatic ring that features slow extraction.

As essentially all accelerator design codes do not foresee the use of electrostatic elements for beam transport and modulation purposes, new tools and methods had to be developed to study the USR beam dynamics in detail. Studies have been done into the long term beam kinetics [5], as well as into comparison between different established and purpose-written computer codes [6].

Beam Diagnostics

The low energy, intensity and variable pulse structure of the antiproton beam in the USR from nanosecond pulses to a DC beam, require the development of new beam diagnostics methods as most conventional techniques used in medium and high energy accelerators will not work. As part of the QUASAR Groups activities, the required beam instrumentation for the commissioning of the USR with proton/H^- beams was developed, as well as specialized diagnostics for the operation with antiproton beams. A compact Faraday cup was designed and optimized to the energy region of interest. Its aperture size allows for the measurement of large beams with a maximum diameter of up to 20 mm. The cup has been manufactured and assembled and was used for first tests with beam [7]. For non-destructive beam position determination, up to eight capacitive pick-ups (PUs) will be installed at the USR. The expected weak signals require the use of high input resistance, high gain/low noise amplifiers, together with a narrowband processing system. A prototype pickup has been developed, built up and tested in a purpose-built test stand [8]. A scintillator-based monitor will deliver information on the transverse beam profile. For similar applications, limited sensitivity and decreased light yield due to surface sputtering had been reported previously. The Group carried out experiments with low energy and low intensity proton beams at INFN-LNS. The possibility for monitoring beams at intensities and energies comparable to those expected at FLAIR was successfully demonstrated [9].

In addition to the above monitors, an ionization beam profile monitor relying on a supersonic gas-jet shaped into an extended thin curtain was developed. While the stored beam crosses the jet, ionization occurs. These ions are then accelerated by an electric extraction field towards an amplification stage with an MCP and detected via a phosphor screen and a CCD camera. Detailed investigations into the process of gas jet formation have been realized. These studies helped improve the understanding of the dynamics of such jets and indicated ways to control the jet properties [10]. The jet has been

[#]carsten.welsch@quasar-group.org

assembled at the Cockcroft Institute and first experimental results are presented elsewhere at this conference [11].

Additional Electrostatic Ring R&D Work

A fixed energy electrostatic storage ring and a low energy injector have been developed by the QUASAR Group in collaboration with KACST researchers. The beam optical and mechanical design of all injector and ring components has been finalized. All parts of the injector have been manufactured and will be assembled in 2011 [12]. A small electrostatic ring, to be placed after the Musashi trap at the Antiproton Decelerator at CERN, has also been designed [13]. This small fixed-energy electrostatic ring is a prototype of the USR for storing antiprotons at energies of around 20 keV. As part of this study, the beam extraction and transport system after the Musashi trap has been studied in detail and suggestions for improvements on the existing beam extraction and transport system have been made. Moreover, a short electrostatic accelerating and matching section has been developed, which shall be placed between the trap and the ring to accelerate the antiprotons from the trap extraction energy to the final required energy [14]. The mechanical design of all components has been finalized and the ring design has been modified so it can be used to store a very wide range of different ion types [15].

SUPERCONDUCTING ACCELERATORS

The Group has been contributing to an international effort in optimizing superconducting cavities for future high gradient accelerators. The effects of higher order modes (HOM) on the particle beam were studied and different superconducting materials were characterized in a quadrupole resonator at CERN.

HOM Studies

HOMs can severely limit the operation of superconducting cavities in a linear accelerator with high beam current, high duty factor and complex pulse structure. The full HOM spectrum has to be analyzed in order to identify potentially dangerous modes already during the design phase and to define the resulting damping requirements. For this purpose a dedicated beam simulation code, Simulation of higher order Mode Dynamics (SMD), focused on beam-HOM interaction was developed, taking into account important effects such as for example the HOM frequency spread, beam input jitter, different chopping patterns, as well as klystron and alignment errors. SMD was used to investigate in detail the influence of HOMs in the Superconducting Proton Linac (SPL) at CERN and their potential to drive beam instabilities in the longitudinal and transverse planes [16]. It was also the basis for more general consideration on the optimum choice of frequency and geometrical beta [17].

SC Materials for High Gradient Cavities

New results on the intrinsic limitations of SC Niobium surfaces for accelerator applications when exposed to RF fields were obtained. For this purpose, a quadrupole resonator has been refurbished with regard to measurement precision and automation. In experimental studies, it was confirmed that the magnetic superheating field is the final limitation for Niobium under RF. The frequency dependence of the residual surface resistance of different materials has been measured and surface analyses have been carried out [18].

MEDICAL APPLICATIONS

The use of accelerators for medical applications has become increasingly important. Ions offer an increased precision in radiotherapy due to their specific depth-dose properties. This precision, however, can only be fully exploited if exact knowledge of the particle beam properties, as well as the exact range of the particles in the inhomogeneous target, is available. To this end, a monolithic active pixel sensor, designed for dead time-free operation, was used as the basis for a beam monitoring system capable of monitoring pulsed and continuous beams. Both, antiproton and carbon ion beams were measured at typical therapeutic energies and intensities and a substantial improvement over previous beam monitors was demonstrated [19]. In addition, a detector set-up, based on a silicon pixel detector developed for the ALICE experiment, was installed at CERN to demonstrate the feasibility of detecting the distal edge of the Bragg peak in antiproton beams by detecting the pions resulting from antiproton-nucleon annihilations [20]. In collaboration with the Clatterbridge Centre for Oncology, the Group has also started investigations into energy spread, intensity and transverse profile measurements which aim at improving the overall facility performance.

BEAM DIAGNOSTICS

The QUASAR Group is coordinating the Marie Curie ITN DITANET, the largest-ever EU funded research and training network on beam diagnostics for accelerators. The network's broad research program covers low and high energy accelerators, both for electrons and ions. Collaboration between the 27 partner institutions and in particular between the academic and industry sectors is an integral part of DITANET. Besides carrying out a cutting edge research program, the network organizes numerous international schools, topical workshops and an international conference at the end of 2011 [21, 22].

LHC Longitudinal Density Monitor

Synchrotron radiation has been used on the LHC for beam imaging and for monitoring the proton population in the 3 μs abort gap since the start of the machine. In addition to these detectors, the longitudinal density profiles of the LHC beams has been measured with a high dynamic range and improved time resolution to allow for the precise measurement both of the bunch shape and the number of particles in the bunch tail. A system based on counting synchrotron light photons with an avalanche photo-diode (APD) operated in Geiger mode has been successfully used in the machine [23].

Beam Loss Studies

A powerful beam loss monitoring (BLM) system is a key element of any high energy accelerator. It is a particular challenge in the case of CLIC as this machine uses a unique two-beam acceleration scheme, where an intense "Drive Beam" generates the accelerating field for a second "Main Beam" linac. The simultaneous detection of losses from both accelerators is a great challenge and is under investigation by the Group in collaboration with CERN. The primary role of the BLM system is to detect potentially dangerous beam instabilities. In addition, it can be used to measure the time structure of the losses and thus indicate the origin of beam perturbations. Extensive Monte Carlo simulations with the FLUKA and Geant4 codes have been carried out for the specific geometry of the CTF3 facility [24]. This provided information about the required dynamic range and sensitivity of the system. In parallel, experimental tests with different detector technologies have started at CTF3.

ACKNOWLEDGEMENTS

The QUASAR Group is grateful for the fruitful cooperation with our colleagues at DKFZ, GSI, HIT, INFN, JINR, KACST and in particular the support by its host institutes MPI-K, CERN, and the Cockcroft Institute. The generous support of the Helmholtz Association of National Research Centers and GSI under contract VH-NG-328, the EU under contracts PITN-GA-2008-215080 and PIIF-GA-2009-234814, DFG under contract WE3565/5 and STFC is acknowledged.

REFERENCES

[1] C.P. Welsch, et al., “FLAIR – A Facility for Low-Energy Antiproton and Ion Research at GSI“, Hyperfine Interactions, **172** (2007) 71-80
[2] C.P. Welsch et al., “An Ultra-low-energy Storage Ring at FLAIR”, Nucl. Instr. Meth. A **546** (2005).
[3] A. Papash, C.P. Welsch, “Realization of Nanosecond Antiproton Pulses in the Ultra-low Energy Storage Ring“, Nucl. Instr. and Meth. A **620** (2010)
[4] G.A. Karamishev, et al., “Study of Slow and Fast Extraction for the Ultralow Energy Storage Ring USR“, Part. Phys. Nucl. Lett. **8** (2011) 50-60
[5] A.I. Papash et al., “Long Term Beam Dynamics in Low Energy Electrostatic Storage Rings“, Proc. IPAC, San Sebastian, Spain (2011)
[6] D. Newton et al., “Investigations into Non-linear Beam Dynamics in Electrostatic Storage Rings“, Proc. IPAC, San Sebastian, Spain (2011)
[7] J. Harasimowicz, C.P. Welsch, “Faraday Cup for Low-energy, Low-intensity Beam Measurements at the USR”, Proc. BIW, Santa Fe, NM, USA (2010)
[8] J. Harasimowicz et al., “Experimental Results from Test Measurements with the USR Beam Position Monitoring System”, Proc. IPAC San Sebastian, Spain (2011)
[9] J. Harasimowicz, et al., "Scintillating Screens Sensitivity and Resolution Studies for Low Energy, Low Intensity Diagnostics", Rev. Sci. Inst. **81** (2010)
[10] M. Putignano, et al., "A fast, low perturbation ionization beam profile monitor based on a gas-jet curtain for the ultra low energy storage ring", Hyperfine Interact. **194** (2009) 189-193
[11] M. Putignano et al., “Commissioning of the Detection System for a Supersonic Gas-jet-based Transverse Beam Profile Monitor”, Proc. IPAC San Sebastian, Spain (2011)
[12] MOA El Ghazaly, et al., "Layout of a Novel Electrostatic Storage Ring at KACST", Appl. Math. Inf. Sc. **3** (2009) 301
[13] M.R.F. Siggel-King, et al., "Electrostatic Low-Energy Antiproton Recycling Ring", Hyperfine Interactions **199** (2011)
[14] O. Karamyshev et al., “Design of an Antiproton Injection and Matching Beam Line for the AD Recycler Ring”, Proc. IPAC San Sebastian, Spain (2011)
[15] M.R.F. Siggel-King, et al., “Design of a Low Energy Ion Beam Facility”, Proc. IPAC San Sebastian, Spain (2011)
[16] M. Schuh, et al., "Influence of Higher Order Modes on the Beam Stability in a High Power Superconducting Proton Linac", PRST-AB 051001 (2011)
[17] M. Schuh et al., “Some Considerations on the Choice of Frequency and Geometrical Beta in High Power Proton Linacs in the Context of Higher Order Modes”, Proc. IPAC, San Sebastian, Spain (2011)
[18] T. Junginger, et al., "RF and Surface Properties of Superconducting Samples", Proc. IPAC, San Sebastian, Spain (2011)
[19] R. Boll, et al., “Using Monolithic Active Pixel Sensors for Fast Monitoring of Therapeutic Hadron Beams”, Rad. Meas. (2011)
[20] S. Sellner, C.P. Welsch, M. Holzscheiter, “Real Time Imaging of Antiprotons Stopping in Biological Targets – Novel Uses of Solid State Detectors”, Rad. Meas. (2011)
[21] http://www.liverpool.ac.uk/ditanet
[22] C.P. Welsch, “DITANET - Investigations into Accelerator Beam Diagnostics”, Proc. IPAC, San Sebastian, Spain (2011)
[23] A. Jeff, et al., " First Measurement Results of the LHC Longitudinal Density Monitor", Proc. IPAC, San Sebastian, Spain (2011)
[24] M. Panniello, et al., “Comparative Studies into 3D Beam Loss Simulations”, Proc. IPAC, San Sebastian, Spain (2011)