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Storage Rings

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DISCLAIMER

0.0.1 Storage Rings

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Storage rings are circular machines that store particle beams at a constant energy. Beams are stored in rings without acceleration for a number of reasons (Tab. 1). Storage rings are used in high-energy, nuclear, atomic, and molecular physics, as well as for experiments in chemistry, material and life sciences. Parameters for storage rings such as particle species, energy, beam intensity, beam size, and store time vary widely depending on the application. The beam must be injected into a storage ring but may not be extracted (Fig. 1). Accelerator rings such as synchrotrons (Sec. **??**) are used as storage rings before and after acceleration.

Table 1: Storage ring applications with examples of past, existing, and planned machines.

Beam accumulation: AA, AR, CR, EPA, MIMAS, RESR, RR, PAR, PIA, PSR, SNS
Beam quality improvement: LEIR, ILC DR
Stretcher, slow extraction: ELSA, KSR
Synchrotron light source: ALS, APS, AS, BESSY, CLS, ESRF, INDUS, NSLS, PSL, DIAMOND, SOLEIL, SLS, Spring-8
Collision, internal target: COSY, HERAe, HESR, IUCF, MIT-Bates, Nuclotron
Collision, other beam: AdA, BEPC, KEKB, RHIC, HERA, LHC, Tevatron, VEPP-2000
Stored beam experiments: ASTRID, ESR, g-2, pEDM, TARN, TSR, UMER

Particles stored in rings include electrons and positrons; muons; protons and anti-protons; neutrons; light and heavy, positive and negative, atomic ions of various charge states; molecular and cluster ions [1], and neutral polar molecules. Spin polarized beams of electrons, positrons, and protons were stored. The kinetic energy of the stored particles ranges from 10^{-6} eV [2] to 3.5×10^{12} eV (LHC, 7×10^{12} eV planned), the number of stored particles from one (ESR) to 10^{15} (ISR).

To store beam in rings requires bending (dipoles) and transverse focusing (quadrupoles). Higher order multipoles are used to correct chromatic aberrations, to suppress instabilities, and to compensate for nonlinear field errors of dipoles and quadrupoles. Magnetic multipole functions can be combined in magnets. Beams are stored bunched with radio frequency systems, and unbunched. The magnetic lattice and radio frequency system are designed to ensure the stability of transverse and longitudinal motion (Sec. **??**). New technologies allow for better storage rings. With strong focusing the beam pipe dimensions became much smaller than previously possible. For a given circumference superconducting magnets (**??**) make higher energies possible, and superconducting radio frequency systems (**??**) allow for efficent replenishment of synchrotron radiation losses of large current electron or positron beams. Storage rings have instrumentation (**??**) to monitor the electrical and mechanical systems, and the beam quality. Computers are used to control the operation (**??**). Large storage rings have millions of control points from all systems.

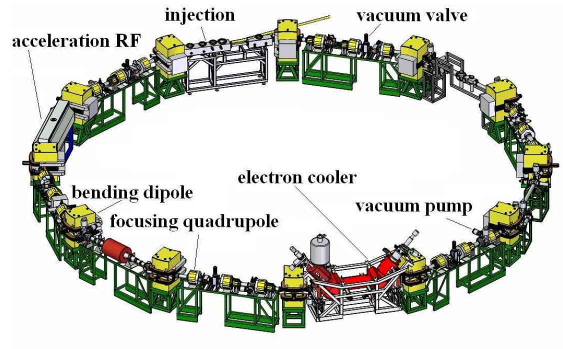

Table 1: Small storage ring (CRYRING at the Manne Siegbahn Laboratory) with main components labeled.

The time dependent beam intensity $I(t)$ can often be approximated by an exponential function

$$I(t) = I(0)\exp(-t/\tau) \qquad (1)$$

where the decay time τ and, correspondingly, the store time ranges from a few turns to 10 days (ISR). τ can be dominated by a variety of effects including lattice nonlinearities (Sec. **??**), beam-beam (Sec. **??**), space charge (Sec. **??**), intra-beam and Touschek scattering (Sec. **??**), interaction with the residual gas or target (Sec. **??**), or the lifetime of the stored particle. In this case, the beam lifetime measurement itself can be the purpose of a storage ring experiment [1].

The main consideration in the design of a storage ring is the preservation of the beam quality over the store length. The beam size and momentum spread can be reduced through cooling (Sec. **??**), often leading to an increase in the store time. For long store times vacuum considerations are important since the interaction rate of the stored particles with the residual gas molecules is proportional to the pressure, and an ultra-high vacuum system may be needed (Sec. **??**). Distributed pumping with warm activated NEG surfaces or cold surfaces in machines with superconducting magnets are ways to provide large pumping speeds and achieve low pressures even under conditions with dynamic gas loads.

The largest application of storage rings today are synchrotron light sources (Sec. **??**), of which about 50 exist world wide.

In experiments where the beam collides with an internal target or another beam, a storage ring allows to re-use the accelerated beam many times if the interaction with the target is sufficiently small. In hadron collider and ion storage rings store times of many hours or even days are realized, corresponding to up to 10^{11} turns and thereby target passages. Ref. [3] is the first proposal for a collider storage ring.

A number of storage rings exist where the beam itself or its decay products are the object of study.

Bibliography

[1] M. Larsson, Rep. Prog. Phys. **58**, pp. 1267-1319 (1995).

[2] K.-J. Kügler, W. Paul, and U. Trinks, Phys. Lett. B, Vol. 72, Issue 3, p. 422-424 (1978).

[3] G. O'Neill, Phys. Rev. **102**, pp. 1418-1419 (1956).

[4] Yu.A. Litvinov et al., Nucl. Phys. A **756** 3 (2005).