Beam dynamic simulations for the superconducting synchrotron SIS300 at FAIR

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Synchrotron and storage rings complex maximum energy achievable: 300Tm or 32GeV/u from SIS300

SIS300 basic requirements:
- in SIS100 tunnel
  - fixed radius
  - B up to 4.5T
  - superconducting magnets
- parallel operation to serve different experiments (CBM, RIB)
  - fast cycling

SIS300 ring has a 6-fold periodicity
One period of the machine:

- arc section
- straight section
- bending magnet
- focusing quadrupole
- defocusing quadrupole
- horizontal chromatic sextupole
- vertical chromatic sextupole
- extraction sextupole

Beam dynamics at slow extraction

Slow extraction from SIS300 to the fragment separator and the experimental caves is achieved by controlled excitation of a third integer-resonance in the horizontal plane

1 - ideal linear lattice:
  natural chromaticity, unlimited DA

2 - adding chromatic sextupoles:
  matched to fulfill Hardt condition (momentum independent of extraction trajectory) to avoid beam losses
  ⇒ still linear chrom and DA 1 order > acceptance

3 - adding resonant sextupoles ⇒ still Hardt condition fulfilled (sext. compensate each other)

4 - adding field errors ⇒ b3 ⇒ chromatic sextupoles have to be matched again to Hardt's condition

Beam dynamics at slow extraction

- Phase space restricted by triangular separatrix
- Particles on separatrix are unstable, drift along it from turn to turn direction the septum aperture

Current effects in Superconducting Magnets

Magnetic field quality in SC magnets is determined by cable positioning and current effects (static and time-dependent)

- Persistent currents, its decay at constant current and reinduction (snapback)
- Field periodic pattern
- Coupling currents (between strands and between filaments) during ramps

Superconducting cable made of hard superconductor
  ⇒ hysteresis-like behavior (ramp rate dependent amplitude)
  ⇒ memory effects = dependence on previous cycles (powering history).

Motivation: new facility FAIR at GSI

References

Field Quality vs. Beam Dynamics

Magnetic field expanded in Taylor series

\[ B_x + iB_y = B_0 + \sum B_n \left( \frac{z}{R_s} \right)^n \]

components allowed depending on magnet symmetries

1st step: static field errors
Field errors corresponding to the cycle flat top (4.5T) simulated with ROXIE

2nd step: time dependent field errors
Estimated variation of dynamic DA along a standard ramped cycle

At other facilities with SC magnets and lighter operation requirements (Tevatron, Hera, RHIC) the presence of:
- Non-allowed components (along whole cycle)
- Time dependent components (injection, flat top)
- Ramp rate dependent components (ramps)

\[ f = 1 \quad f = 3 \quad f = 5 \]
\[ f = 7 \quad f = 10 \quad f = 20 \]

Only particles with y=0 are actually reaching the separatrix, others have DA so small that are lost (unstable) before reaching separatrix

Studying extraction dependency of allowed errors with a multiplicative factor f

Studying extraction dependency with skew errors

Studying extraction dependency with skew errors