Spin Simulations Using the Bmad Toolkit

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In the Beginning…

Brief History:

• Bmad is a **software toolkit** for the simulation of charged particles and X-rays.
• Born at Cornell in mid 1990’s
• Started life as modest project: Just wanted to calculate Twiss functions and closed orbits.
• Initially Bmad used a subset of the MAD lattice syntax. Hence the name: “Baby MAD” or “Bmad” for short.

Over the years Bmad had evolved…
And Baby Grows Up...

Currently:
  • ~100,000 lines of code
  • ~1,000 routines

And it can do much more:
  • Lattice design
  • X-ray simulations
  • Spin tracking
  • Wakefields and HOMs
  • Beam breakup simulations in ERLs
  • Intra-beam scattering (IBS) simulations
  • Coherent Synchrotron Radiation (CSR)
  • Touschek Simulations
  • Frequency map analysis
  • Dark current tracking
  • Etc., etc.
Overview

- Written in Fortran 2008.
- Object oriented from the ground up.
  
  ```fortran
  type (lat_struct) lat
  call bmad_parser ('lat.bmad', lat)
  ```
- Has structure translation code for interfacing with C++.
- With certain restrictions, Bmad can be run multi-threaded.
- Lattice files use a MAD like syntax.
- Well documented (Manual is ~500 pages).
- Open Source: http://www.lepp.cornell.edu/~dcs/bmad/
Advantages of a toolkit:

• Cuts down on the time needed to develop programs.
• Cuts down on programming errors (via code reuse).
• Provides a simple mechanism for lattice function calculations from within control system programs.
• Standardizes sharing of lattice information between programs.
Bmad Ecosystem

Due to its flexibility, Bmad has been used in a number of programs including:

- **Tao**: General purpose design and simulation.
- **Synrad3d**: 3D tracking of synch photons, including reflections, within the beam chamber.
- **Cesrv**: On-line data taking, simulation, and machine correction for CESR.
- **dark_current_tracker**: Dark current electron simulation.
- **freq_map**: Frequency map analysis.
- **ibs_sim**: Analytic intra-beam scattering (IBS) calculation.
- **touschek_track**: Tracking of Touschek particles.
- **etc...**

**Code reuse**: Modules developed for one program can, via Bmad, be used in other programs.
Problem: Bmad is not a program so it cannot be used “out of the box.” for simple calculations.

Solution: Develop Tao - a general purpose simulation & design program (like MAD) with
- Twiss and orbit calculations.
- Nonlinear optimization.
- Spin tracking.
- Etc.

Additionally: Tao’s object oriented coding makes it relatively easy to extend it.
- For example: Can add custom tracking code to enable Tao to handle new depolarization effects.

Tao with Bmad gives the flexibility of a library with the convenience of a program.
Spin Tracking

- Bmad can track a particle’s spin including EDM and fringe fields.
- Bmad can track the orbit & spin of a particle through arbitrary fields.
- Bmad can produce transfer maps which include spin.

### Phase Space Map

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### Spin Map

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Spin Studies

Bmad has been used for spin simulation studies for:

- Fermilab g-2 ring.
- ILC.
- Julich: Studies for future electric dipole moment (EDM) measurements.
- Spin matching in Jefferson Lab’s planned electron ion collider.
Dave Rubin at Cornell has been developing a simulation program to simulate the Muon g-2 experiment at Fermilab.

Need to simulate:
- Injection line into storage ring.
- Three dimensional field of the injection line.
- Scattering of muons as they cross the inflector wall
- Electrostatic quadrupoles
- Muon decay
G-2 Simulation

Bmad provides:
- Ability to define the geometry of the injection line and storage ring.
- Ability to define the geometry of the inflector wall.
- Ability to define custom fields for the injection line and electrostatic quads.

Needed to develop for the program:
- Tracking of muons through the inflector wall
- Muon decay [will be ported to Bmad]
Conclusions

• Bmad is an open source software library for simulating charged particle beams (and X-rays).

• Bmad can construct symplectic maps with spin for normal form analysis, resonance strength analysis, spin invariant map analysis, analysis of chromatic aberrations, etc.

• Bmad can handle element misalignments, high energy space charge, wakefields, elements with arbitrary fields, etc.

• Bmad can handle complicated lattice geometries such as injection lines, extraction lines, dual ring colliding beam machines, etc.

• Bmad comes with an ecosystem of programs for lattice design, dynamic aperture calculations, Touschek simulation, etc., etc.

• If new types of simulations are needed, with Bmad, new simulation programs can be developed in less time and with less effort and with fewer bugs.

• Bmad has been successful due to it’s modular, object-oriented design which allows it to be adapted to ever changing simulation needs.