Modelling Needs for Future Colliders

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AOC Workshop
05 February 2015

Model

a simplified representation or description of a system, phenomenon or complex entity,
together with any hypotheses required to describe the system or explain the phenomenon.
Esp. one designed to facilitate calculations and predictions.

Physical world – Model – Equations

Simplified Representation of Reality

A model

- is inevitably limited
- contains assumptions and hypotheses

- How simple can a model be ?
- How complex can we make it ?
- What assumptions are taken ?
- What part of reality do we model ?
- Known physics law or experimental fit ?

Facilitate calculations or predictions

- Never lose this aim !
- Make it as simple as possible (KISS) and as complex as necessary

This could have considerable impact eg on design and simulation codes.

Simplified Representation of Reality

- What hypotheses and assumptions ?

  Take the habit to state these clearly, document them and respect them.

  e.g. $\beta = 1$ (and life is so much simpler)

- What (small) part of reality is covered ?

  "we ignore beam-beam, nonlinearities beyond second order, coupling, thick lenses, chromatic effects and misalignments…"

Future Colliders (HL-LHC, FCC-pp, FCC-ee, ILC)

- Large and complex
  - High number of components, systems…
  - High number of variables
- High Power stored (beams and systems)
- Collective effects (BB, SPC, WF, beam loading…)
- Energy
  - Fixed (HL-LHC, FCC…) or steady state
  - Variable (ILC)
- Linear vs. circular

Accelerator Model Components

- **Data** : physical description of accelerator elements, systems, relations…
- **Engines** : software packages
  - Physics: objects and methods
  - Mathematical methods and algorithms
- **User Interface** : scripts, GUI, data representation, etc…

Models evolve

- Data: different design cases, different actual configurations (versioning…). Data can come from several sources.

- Different engines or codes, each with their sets of limits and their assumptions, and their versions, bug fixes and improvements…

- Benchmark one against the others
- Test any change for regression or side effect

When a model is "wrong"…

- Was there any change to input data ?

- Are you within the validity domain ?
- Are you stable from math and algorithm standpoint ?

- Should you add some more reality, i.e. add complexity ?

Modelling needs (design)

- Single particle dynamics for lattice design
- Linear and non-linear optics to reasonably high order with good insight in interplay, feed-down, etc.
  - SC magnets (HL-LHC, FCC-pp)
  - Final Focus System (ILC and FCC-ee)
- Robustness and tuneability studies

Modelling needs (design)

- Tracking:
  - longer term effects (DA, stability): good for verification but it can use a different model…
  - steady state (radiation)
  - Monte Carlo techniques

- Time variations: dynamic processes, optics changes, levelling, ripple, RF trip…

Modelling needs (design)

- Collective effects: fundamental in all cases.
- Radiation models: systematic (optics) and stochastic (tracking)
- Investigate failure scenarios and machine protection measures.

Modelling needs (design to ops.)

- Design and validate tuning procedures
  - One by one and in conjunction
- MD preparation and rehearsal
- Operator training (“flight simulator”)

Modelling needs (operations)

- Online model
  - "What if " scenarios:
    provides crew with on-demand information or informs crew of potential issues
  - Monitoring or follower mode:
    provides a check of the quality of the model

- Offline model
  - Studies, eg MD replays.

Time issues

- Offline:
  - Design (before operation)
  - Analysis, postmortem (after operation)
- Online:
  - “synchronous” with events, given a timescale.
  - Can lead or trail… ie model usage comes before or after the event.

Modelling needs (operations)

Integration within control system

"Cultural" issues in development and environment

Orbit control: linear pre-calculated response matrix (may require iterations), or recalculated response matrix, or matched in real time…

Replace pre-calculated flat-file knobs (tune, chroma…) with on the fly recalculations or rematching based on current situation ?

Data exploration

- Logging systems typically collect huge amount of data
- Any relationship between two variables (equation) should be present as correlation in logged data.
- Correlation plots… or data mining ?

Data mining

- Informed:

  Check known correlations (physics) and monitor validity of model.

- Exploratory

  Look for correlations: known and explained is physics; tag it as boring, the rest is exciting.

Model Agent

- seconding the ops crew with a model agent that knows accelerator physics, actual accelerator configuration and status, knows what is happening in the control system in real time and computes very fast…

- agent can acquire data or fetch it from measurements or logging to prepare or make informed decisions.

Model Agent

- Still not too far from combination of sequencer and state machine…
- model agent can observe and record human action in a given situation and compare it to outcome in order to collect positive experience and wisdom, i.e. learn from operators…

Key messages to conclude

Model definition

- A model is an approximation
  - What is the validity domain ?
  - What is the physics content ?
- Multiple models are required
  - Each adapted to some issues, and a phase in lifecycle
- Check and benchmark regularly

Model integration

- Integrate as early as possible into the control system development

- This will have consequences on all, models and control systems,
so think ahead

- Aim for easy and seamless transition between online and offline studies.

Models in the future…

Think far and wide!

- Data mining is one area where automated processes can do much more than people

- Model agents or operator assistant
  … where the system
  "accelerator + skilled operator" becomes the object of the model