

## **KURRI FFAG Simulation Plan – second draft**

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### **I. Two main objectives**

1. Develop simulation codes for FFAG accelerators. Code/s should be able to simulate several key functions such as acceleration and space charge effects. Take an idealized KURRI FFAG as a model lattice at the start.

- A model lattice does not have to have all the details as opposed to the second objective.
- Benchmark ZGOUBI & OPAL among other codes basic dynamics (transverse & longitudinal).

2. Obtain a better understanding of the KURRI FFAG by comparing models with measurements. Use the model to:

- Increase the performance of the existing machine
- Guide modifications
- Investigate intensity limits

First step is for everyone who wants to use/benchmark simulation codes (Zgoubi, OPAL and EARLITIMES or KURRI in-house codes in particular) for their own FFAG design and simulation study. Second step is more KURRI FFAG oriented. The results may not be obtained by a single procedure of a particular code, but we may employ combination of

several codes or combination of codes and theoretical models (e.g. foil scattering).

## **II. Information for simulations:**

A site for the benchmarking has been set up here:

<http://hadron.kek.jp/FFAG/colabo/simulation/>

- Lattice magnet specification.
- RF parameters

Field maps in TOSCA for the KURRI FFAG as well as existing work on ZGOUBI (Malek) and OPAL (Chris R) can be found on the github:

<https://github.com/fixed-field-acceleratorsimulation>

Further information and presentations from meetings can be found on:

<http://hadron.kek.jp/FFAG/colabo/>

The RF program is for simulated variable-k setup (current real experimental setup) - note that the time and RF frequency in this file is what is 'real' the other parameters in the files are assumed including the energy gain and radius.

In future could also use the field maps generated from ZGOUBI if codes are linked up to generate maps (S. Tygier & F. Meot)

### III. Objective 1 (Generic FFAG simulation):

#### Benchmark step 0:

**Simulation codes to be used for this study (Zgoubi, OPAL and others) should be benchmarked by the following test. This tells you whether the simulation codes give the same results on the very basic level.**

#### 1. Without rf

1.1 Transverse tune and revolution frequency (or time) vs momentum (5 or more points in the range between injection and extraction) with small amplitude particles.

1.2 Direct comparison of transverse phase space trajectory which also shows physical/dynamic aperture. In order to do this test, we have to define initial conditions. Usually we start with 2D phase space with zero amplitude in other plane, but some test should include all finite 4D initial coordinates to start with.

1.3 Transverse amplitude dependence of transverse tune and revolution frequency (or time).

#### 2. With rf but without acceleration (or constant rf frequency)

2.1 Direct comparison of longitudinal phase space trajectory which also shows the size of rf bucket. We assume small amplitude particles in transverse, but could include large amplitude particles as well.

2.2 Synchrotron tune vs longitudinal amplitude. This test could be done at several momenta (5 or more points in the range between injection and extraction).

2.3 Check the transverse phase space as well when particles are oscillating in a longitudinal rf bucket.

#### 3. With acceleration (or with rf frequency modulation)

3.0 Use the "standard" two tables (rf voltage vs time and rf frequency vs time).

3.1 Direct comparison of longitudinal phase space trajectory which shows the accelerated particles. In order to compare, we need to define coordinate system. One way is to take rf phase vs relative momentum from "synchronous" particle. The other way is to take rf phase vs absolute momentum. Instead of taking rf phase, we can also take time as one axis. I prefer either (phase vs absolute momentum) or (time vs absolute energy) in fixed field accelerators. Those are canonical conjugate variables.

3.2 Transverse tune as well as synchrotron tune vs momentum (or time). This may need a technique to measure tune with small number of turns such as NAFF (Numerical Analysis of Fundamental Frequency). Then we also need to specify the window size; how many consecutive turns we should use to calculate instantaneous tune.

### **Benchmark step 1:**

**Once the single particle tracking looks reasonable, track matched distribution without and with acceleration. Establish “diagnostics” in the simulation.**

#### 1. Without acceleration

- 1.1 See transverse and longitudinal emittance and twiss parameters of the beam does not change if the initial beam is matched.
- 1.2 With foil scattering, emittance growth and increase of momentum spread should be observed. Results should be compared with analytical value as well as other codes.

#### 2. With acceleration

- 1.3 Physical emittance should follow adiabatic damping both in transverse and longitudinal.

### **Benchmark step 2:**

**The last step is to see intensity effects.**

#### 1. Without acceleration

- 1.1 It is nice to be able to calculate initial matching condition with space charge effects (rms sense for example) although this probably is not much away from that for zero current.
- 1.2 When space charge effects are switched on, emittance may increase. Calculate emittance growth vs intensity.
- 1.3 In addition to space charge effects, foil also makes emittance growth. Now we can see both effects at the same time.

#### 2. With acceleration

- 2.1 As the beam momentum increase, space charge effects decrease. Emittance growth with space charge will be reduced in the later cycle. This can be confirmed first without foil scattering.
- 2.2 Because of the finite size of stripping foil, the foil scattering will stop when the beam escapes from the foil region. We should see this.

#### **IV. Objective 2 (KURRI FFAG specific):**

##### **Benchmark step 1:**

##### **Simulate several key observations without space charge effects.**

- Modeling of COD by the influence of the RF cavity interaction with the magnetic field in the straight sections.
  - It can be included as a thin lens kick once the integrated strength is given.
  - Input of more details such as 3D field map of the RF straight section, distorted field by septum, field profile with “patch” will be the second step.
  - Correction elements on both sides of the cavity should be modeled.
- Modeling of injection line from the linac exit to the foil in the ring.
  - From the linac exit to “matching point”, magnets can be hard edge or soft edge.
  - From “matching point” outside of the ring to the foil, better to use TOSCA field map.
- Understand the COD and its effects on other measurements including tune, dispersion etc
  - Calculate tune at injection momentum with and without COD.
  - Calculate dispersion function at S\* (measured position at the experiment) with and without COD.
- Calculate tune vs momentum with TOSCA field map.
- Understand emittance growth and energy loss due to the foil.
  - Geant 4 done by Chris R, compare to models in OPAL
- Understand the rf capture process and beam survival when long bunch (> 1 turn) is injected
  - This has been done by Uesugi for longitudinal dynamics only. Without space charge, the full simulation with transverse degree of freedom may not make much difference.

##### **Benchmark step 2:**

##### **Simulate expected observations in future with space charge effects.**

- Can we observe the emittance growth from space charge in this machine? Chris R has studied the foil scattering & foil emittance growth in GEANT 4 but eventually we need to compare to space charge emittance growth as well.
- RF capture and losses through the acceleration cycle - T. Uesugi has already studied this to identify ideal phase and done a lot of work on RF capture with simulation, you can read the results on the hadron.kek server. (Would need to re-do some of this to confirm against existing results and then extend it to include space charge)

- Study whether we need to add additional collimation etc. to avoid machine activation when intensity is increased?
- What is the influence of the vacuum chamber shape? (i.e. we are close to one side of the chamber at injection where space charge is strongest). So we need to include boundary conditions on the simulation.
- + other items

## **V. Other notes**

### **Repository for simulation**

All github/scripts will also be linked from kurriffag google site. Please contact Suzie if you do not have access to this site.

<https://sites.google.com/site/kurriffag/scripts>

### **Diagnostics**

AA will inquire if we could have a wire scanner on loan from PSI. Need a drawing indication the possible location and the dimensions of the flange to mount the wire scanner. In case one can give me the vacuum pressure we can also investigate if a residual gas (CCD based) monitor could work.