

CHEF: Status Report

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What is "CHEF" ?

- A framework for beam dynamics simulations consisting of a set of libaries organized hierarchically + python bindings + a standalone application
 - Written in std C++ (use STL and templates extensively)
 - Most functionality conveniently available through Python bindings.
- Originally designed for proton rings and beamlines; later, adapted for high energy linacs
 - The code provides facilities for both conventional tracking and map computions using automatic differentiation. The same generic code is used for both functions. Since most codes of this kind tend to be dominated by bookkeeping; the code design strives to make bookeeping as generic as possible to minimize need for "re-invention". This makes it straighforward to accommodate special needs.
- Some Distinctive Features:

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- No a-priori, embedded paraxial approximation
- Can accurately accommodate large dp/p
- Consistently uses 6D canonical variables (i.e. px/p , not x')
- No a-priori embedded relativistic (beta ~ 1) approximation
- In principle, can track phase space "patches" using DA variables.

Some Features of Interest

CHEF			
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LINAC	beamline	0-10899.8	
- • BEG_ELIN1	marker	0	
- • YELIN1I	vkick	0	
	beamline marker	0-1573.76	
- DMLSERVBOX	drift	2.5	
CSTR01	beamline	2.5-145.342	
BEGMESTR F F FFU001	beamline	2.5	
+ RFU002	beamline	37.5854-72.6708	
FRFU003	beamline	72.6708-107.756	
- DMLENDBOX	drift	145.342	
ENDMLSTR	marker	145.342	
GSTR02 BEGMISTD	beamline	145.342-288.183	
- RFU005	beamline	145.342-180.427	
- • BEGMLRFU	marker	145.342	
International Control Contr	beamline	145.342-156.613	
MLCM(MLCAV,KML1,KML1)	beamline	169.156-180.427	
- • ENDMLRFU	marker	180.427	
+ BEGMIREU	marker	180.427-215.512	
# IMLCM(MLCAV,KML1,KML1)	beamline	180.427-191.698	
MLCMQ(MLCAV,QML006,MML006,XML006,YML006,MQD,KMLQ,KMLQ)	beamline	191.698-204.241	
ENDMLRFU	marker	204.241-210.012 215.512	
- RFU007	beamline	215.512-250.598	
- • BEGMLRFU	marker	215.512	
BEGMLCM	marker	215.512	
er ∎ KML1	beamline	215.512-215.512	
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- DMLCAVF2C	drift	216.76	
- DMLCAVF2F	drift	216.832	
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- DMLCAVF2C	drift	218.079	
- DMLCAVF2F	drift	218.151	
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A browser to study the lattice and its hierarchical organization (full support for XSIF format)

User-friendly optics computations and display capabilities. Traditional (uncoupled) or generalized (coupled) lattice functions.

CHEF vs Lucretia Circa 2008

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Agreement with other codes was generally ok, nevertheless, some differences remained unexplained.



What has changed ...

- Cavity tilt angle conventions
- Conversions between canonical and optical variables
- Initial distribution generation (small error in the generated momentum distribution)
- Fixed problem with cavity focusing
- Etc ...

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No single dominant factor.

Trajectory in Misaligned Linac

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Y Trajectory w/misalignements 0,001 0.0008 0.0006 0.0004 Y [h] 0.0002 0 -0,0002 -0.0004 -0.0006 Ø 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000 **BPM No**

Sample trajectory. Misaligned cavities & quadrupoles

Trajectory Comparison

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Agreement better than 3.0 E-07 m over 20 km

Ver Emittance after DFS Correction



CHEF vs Lucretia - Wakefields OFF

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Ver Emittance after DFS Correction



CHEF vs Lucretia: Wakefields ON

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- We noticed some discrepancies between the nominal dispersion computed by CHEF and other codes.
- The issue is relevant to the extent that optimum corrector settings from the DFS algorithm may be depend on how dispersion is computed.

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Dispersion (MADacc)



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With Acceleration

Dispersion(Lucretia)



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No Acceleration

With Acceleration

Dispersion (CHEF)

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- A curved linac is a bit of an oxymoron ;-)
- In most situations of interest, the nominal dispersion in a linac vanishes (or can be assumed to do so)
- A curved ILC linac is one instance where nominal dispersion is non-zero (albeit small) and matters.
- It is easy to inadvertently compute dispersion under assumptions that are not fully appreciated.

Elementary Dispersion ODE

$$y(s) = y_{0}(s) + \eta_{y}(s)\delta(s) \qquad \delta(s) \equiv \delta p(s)/p_{0}$$

$$\underbrace{\frac{d^2(\eta_{\mathsf{y}}\delta(s))}{ds^2}}_{ds^2} + K(s)\eta_{\mathsf{y}}\delta(s) = \frac{\delta(s)}{\rho(s)}$$

No acceleration:

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$$\delta = \delta p_0 / p_0 = \text{const}$$

For a typical HE linac:

$$\delta(s) = \frac{\delta p_{\mathbf{0}}}{p(s)} = \frac{\delta p_{\mathbf{0}}}{p_{\mathbf{0}}} \frac{1}{(1 + gs/p_{\mathbf{0}})}$$



Matrix codes effectively solve

$$\frac{d^2\eta}{ds^2} + K(s)\eta = \frac{1}{\rho(s)} \tag{1}$$

Which is valid only for $\delta = \delta p_0 / p_0 = \mathrm{const}$

While it is certainly possible to set the cavity gradients so as to keep dp/p constant, this does not correspond to normal operating conditions. In general, the dispersion depends on the specific acceleration profile

How CHEF computes dispersion

- A reference particle is sent through the linac and the magnet field are scaled so as to make the optical strengths constant for that particle.
- Method 1: A "JetParticle is tracked through the linac. A JetParticle propagates the derivative of y w/r to dp/p to machine precision. The result is scaled by p/p0
- Method2: 2 particles with momenta p and p+dp are tracked through the linac. The result is scaled by p/p0.
- Method3: Same as 2, but this time, the acceleration gradient is modified by a factor 1+dp/p so as to make dp/p constant.

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Getting Agreement



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Lucretia, using a custom script rather than the build-in twiss method.

DFS Algorithm

Minimize

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$$\sum w_1(m_j - X_j)^2 + w_2(\Delta m_j - \Delta X_j)^2$$

Where $m_{j}, \Delta m_{j}$ Measured positions and orbit differences $X_{j}, \Delta X_{j}$ Expected (model) positions and orbit differences

The expected difference due to momentum offset is

$$\Delta X_{j} = \eta(s_{j}) \delta p/p(s_{i})$$
 How is η determined ?

Conclusions and Outlook

 Agreement between CHEF and Lucretia is now extremely good; the puzzling small discrepancies observed in recent years are fully understood.

- Other codes like Lucretia and Placet are in routine use at FNAL. In-depth expertise with > 1 code is a valuable asset.
- The manpower dedicated to CHEF is limited; nevertheless, development continues.
- In the course of our studies, we observed some disagreement between the nominal dispersion computed by CHEF and that computed by other codes. The disagreement is understood and results from a different interpretation of 'dispersion'.
- "dispersion" in the context of a linac must be interpreted carefully. In particular, computation of the expected orbit difference induced by a momentum offset in the DFS algorithm may be sensitive to this interpretation.