Preface

Pre-Boarding Announcement

All the examples of this book are derived from a code in which I deliberately put bugs and nonphysical Hamiltonians: the drifts are wrong, the magnets have mistakes, physical constants are wrong, the spin equations are wrong, etc…

Actually I did not have the *cojones* to confuse readers who might actually compare the examples of this book with a standard accelerator code. But it must be the conclusion of the reader who understands this book, that the exactness of the model is totally irrelevant to the general structure of accelerator theory.

Garbage in; garbage out!

If the style of this book is more akin to the pamphleteer style of V.I. Lenin's "State and Revolution" or Thomas Paine's "Common Sense," it is not an accident. I am describing shamelessly my own position and conviction.

Through most of the book I talk in the first person singular. I avoid the scientific "we" or Julius Caesar's "he/one." My reasons are simple: the main idea of this book —the existence of a natural hierarchy—is mine and I will not be a coward. It is not a review article. I am not interested in giving credit to people whose work is irrelevant to mine or, as it is often the case, antithetical to my work. I do not care that they are great accelerator physicists or have contributed valuable insights to the field. I describe here a very narrow and specific topic as I see it. Some people have had some influence on me in relation to this book. I can name them right here: Alex Dragt, Martin Berz, Richard Talman, Ron Ruth, and recently, Desmond Barber. Other people have contributed to the software I used: Martin Berz (again), David Sagan, Frank Schmidt, and Eric McIntosh. Finally, Alexander Molodozhentsev has actually used my work in physical applications which in some ways have motivated me to go further.

When I use the collective "we" in this book, it really means "the reader and I." Of course I am sure that I occasionally use the passive and the "we" whose purpose is to diffuse responsibility—after all I live in Japan where diffusing responsibility is a cultural imperative! I apologise in advance.

This book originates in my conviction that, since 1980 at least, computer simulations of accelerators are ubiquitous and unavoidable. Therefore, as soon as I entered the field I decided that theory and simulation should be adapted to each other.

Accelerator theory, which in its simplest incarnation is called “Courant-Snyder” theory, should be designed with the simulation code in mind. Integrators in accelerator physics, often called “kick codes,” simply push particles around the machine. However, circa 1986, the tools of truncated power series algebra (TPSA) have been made available to the accelerator community primarily through the work of Berz. Thanks to operator overloading, available in C++ and Fortran90, it is possible to write an integrator which can produce automatically[2] not only brute force tracking but approximate Taylor maps.

Taylor maps can be analyzed by a process called normalization. This process allows the Courant-Snyder theory to be extended effortlessly to nonlinearities, spin, radiation, modulated magnets, etc., provided that a normalization library, akin to a diagonalization library, exists and is available.

Once these tools are in place, it is possible to cover the entire field of accelerator perturbation theory, provided one respects and abides by a strict hierarchical code. The word code here means “computer program” and well as behavior.

In this book I display with examples, runnable on any computer platform, the full gamut of this hierarchy: one-turn maps, normalization of one-turn maps, universal Twiss[3] loop and Fourier transform of the Hamiltonian (or Lorentz force) expressed in approximate Floquet variables. This final Hamiltonian is the Hamiltonian often found in standard accelerator textbooks. Here you are told how to *really* compute it in a complex and arbitrary ring; better, you are given some tools that exemplify that power.

I will review the normalization of linear maps in n-degrees of freedom under most regimes: symplectic, radiative, spin, and modulated magnets. I will then proceed to the nonlinear normalization. This will include some examples with a single resonance and a limit cycle. I have also a discussion on spin. I will finish the book with Guignard theory which is the final output of the universal Twiss loop.

It is notable that Guignard theory, which is often the starting point of perturbation theory, is here a final product and thus at the bottom of the hierarchical structure. This is not a matter of taste: any serious calculation which includes errors, fringe fields, and the effect of earthquakes must follow that hierarchy. Of course if one pontificates from a throne in the rarefied air of pure mathematics, then it is a matter of taste. But here I provide real examples, not hot air.

This book is novel in two respects. First, I made an effort to produce examples on which the reader can check his understanding. Unlike most books where examples are trivial or simply absent, here all the tools in the book are available to the reader with 16 examples in the appendices that can be run with freely available

[2]Almost automatically!

[3]Some would prefer the term “universal lattice function loop.”

compilers. The actual ring used is an old design of the Advanced Light Source at the Lawrence Berkeley National Laboratory where I once worked. The lattice is in Appendix A.

Secondly, there are novel topics that are not found in the literature. The chapter on spin contains a few novel ideas mostly due to Desmond Barber and Dan Abell. The chapter on Guignard-like Hamiltonian is totally new and is based on one's ability to take the logarithm of a nonlinear map. The idea is not new to me but I took the time and trouble to implement enough of it for the sake of this book.

Of course I hope that some accelerator physicists will read this book and try the examples; they are the intended audience.

The reader is invited to jump to Chap. 9 and read the conclusion of this book. It mirrors this preface and it is a good way to avoid reading a book!

Finally, I would like to state that I am inspired by the linguist Noam Chomsky in my approach to this field.

First of all, and this is mostly pure coincidence, Chomsky is famous in science for the concept of a universal grammar and the concept of the Chomsky Normal Form (CNF) applied to context free formal grammars. These context free grammars are a little akin to our integrable systems and the CNF to our normal forms. Of course the real universal grammar which is postulated to exist in a child's brain is more complex as is the real dynamics of a symplectic map.

Secondly, and more importantly, I am inspired by Chomsky's political analysis methods. In particular, one can deduce a lot of things by looking at the structure of a system[4] from far above. And, when our logical deductions are wrong, it is instructive since it is often the sign of specific human manipulations. Accelerators are man-made after all. It is logical to assume generically, if we look far above them, that they have linear stability. Without any additional knowledge, I can derive all of Courant-Snyder theory. The details are irrelevant: a marble in a frictionless gutter or a proton in a synchrotron all lead to the same theory. So if one discovers that the *stable* system is linearly unstable, it teaches us a lot about human manipulations. Also, there are many numerical methods that are based on the quasi-failure of integrability: Laskar's frequency analysis is perhaps the most famous. Generally, there is a lot to learn from discovering that certain naive expectations are usually wrong.

Politically the same is true. I expect accelerator laboratories to produce graduate students who are partial slaves simply because of the purpose of accelerator physics. Graduate students are assigned easily to supervisors on the basis of needs because we are a glorified service station. When it is not the case, we can expect that some special mechanism was put in place to prevent exploitation.

A very respected Japanese colleague of mine once told me that "my approach to the theory" is not good because it does not permit the student to jump immediately into useful thesis work. I thought that students are supposed to learn and not to be

[4]To look from far above, keeping lesser details away, is also a method preached by Feynman, who, with Chomsky, is my intellectual hero.

"useful." But this is what happens if you are in a technological field and, worse, in a laboratory with a service mission.

You have been warned: the material of this book is considered useless by my most esteemed colleagues. *Caveat emptor!*

Filling in the Blanks!

This book should be a living document. If you have a powerful library using more sophisticated software and language, I encourage you to redo the examples of this book. If you fail, then your library is deficient or you do not understand the book fully. If you succeed, you have my permission to ask the publisher to republish part of this book verbatim with your own examples and your name above mine!

I strongly feel that theory does not belong to me. It belongs, like any scientific theory, to the community at large. So go ahead and redo the examples with another tracking code and another analysis library!

Tsukuba, Japan Etienne Forest
August 2015

Springer
http://www.springer.com/978-4-431-55802-6

From Tracking Code to Analysis
Generalised Courant-Snyder Theory for Any Accelerator Model
Forest, E.
2016, XXIII, 347 p. 11 illus. in color., Hardcover
ISBN: 978-4-431-55802-6