

Contents

1	Introduction	1
	Ken Takayama and Richard J. Briggs	
	References	5
2	Historical Perspectives	7
	Richard J. Briggs and Glen Westenskow	
2.1	Introduction	7
2.2	Invention of the Linear Induction Accelerator by Christofilos	8
2.3	Early History of Short-Pulse Induction Accelerators at LLNL and LBNL	9
2.4	Long-Pulse Induction Accelerators	13
2.5	High Repetition-Rate Induction Technology Developments	13
2.6	Recirculating Induction Linacs	14
2.7	Former USSR Induction Accelerators and “Coreless” LIA’s	15
2.8	Summary Tables of Induction Accelerators World-Wide	16
	References	19
3	Principles of Induction Accelerators	23
	Richard J. Briggs	
3.1	Introduction	23
3.2	Basic Features of an Induction Accelerator System	23
3.3	Comparison Between RF Accelerators and Induction Accelerators	26
3.4	Physical Processes Inside a Typical Induction Module	28
3.5	Magnetic Core Considerations	32
3.6	Ferromagnetic Laminated Cores	34
3.7	Ferrites	35
	References	36

4	Modulators	39
	Edward G. Cook and Eiki Hotta	
4.1	General Discussion on Induction Accelerator Modulators	39
4.1.1	Line-Type Modulators	40
4.1.2	Solid-State Modulators	50
4.2	Switching Devices	60
4.2.1	Closing Switches	60
4.2.2	Closing Switches with an Opening Capability	69
	References	72
5	Magnetic Materials	75
	Louis L. Reginato	
5.1	Introduction	75
5.2	Ferrites	75
5.3	Ferromagnetic Materials	78
5.4	Energy Loss	81
5.5	Other Materials	83
5.6	Summary	85
	References	85
6	Induction Cell Design Tradeoffs and Examples	87
	Louis L. Reginato and Richard J. Briggs	
6.1	Introduction	87
6.2	Cell Configurations	87
6.3	Long-Pulse Cell Design	91
6.4	Short-Pulse Cell Design	92
6.5	Comparison Between Amorphous and Ferrite Cells	93
6.6	Core Segmentation and Flux Equalizing	95
6.7	Core Reset Techniques	97
6.8	High Voltage Design Issues	97
6.9	Voltage and Electrical Stress Distribution in Laminated Cores	99
6.10	Coupling Impedance	107
6.10.1	General Form of the Transverse Impedance	107
6.10.2	Minimizing the Transverse Impedance in Induction Cell Designs	109
6.10.3	Measurement of the Transverse Impedance	110
6.11	High Average Power	112
6.12	Summary of Cell Design	113
	References	114
7	Electron Induction Linacs	117
	George J. Caporaso and Yu-Jiuan Chen	
7.1	Introduction	117
7.2	Electron Sources	119

7.2.1	Cathodes	119
7.2.2	Electron Guns	120
7.3	Beam Dynamics in Induction Machines	123
7.3.1	Basic Force Equation	123
7.3.2	Coordinate Description of a Beam	124
7.3.3	Focusing in a Solenoidal Field	125
7.4	Envelope Equations	131
7.4.1	Lee-Cooper Envelope Equation	131
7.4.2	KV Envelope Equations	135
7.5	Corkscrew Motion	136
7.5.1	Corkscrew Amplitude	136
7.5.2	Tuning Curve Algorithm	139
7.6	Instabilities	141
7.6.1	Image Displacement Instability	141
7.6.2	Beam Breakup Instability (BBU)	144
7.7	Induction Linac Design Considerations	152
7.7.1	Optimal Focusing Strategy	152
7.8	Nonlinear Focusing to Suppress BBU	155
7.8.1	Motivation for Nonlinear Focusing Systems	155
7.8.2	Laser Generated Ion Channel	155
7.8.3	Phase Mix Damping of BBU	157
	References	162
8	Applications of Electron Linear Induction Accelerators	165
	Glen Westenskow and Yu-Juan Chen	
8.1	Linear Induction Accelerators Built for Flash	
	X-Ray Radiography	167
8.1.1	Induction Accelerators Built for Radiography	167
8.1.2	Beam Requirements	169
8.1.3	Target Issues	171
8.2	Free Electron Lasers Driven by LIAs	171
8.2.1	ELF Experiments on the ETA Accelerator	172
8.2.2	Short Wavelength Radiation Production	
	Using the ATA Accelerator	173
8.2.3	Use of Induction Accelerators to Produce Millimeter	
	Wavelength Power for Tokamak Heating	175
8.3	Two-Beam Accelerators	176
8.4	High Average Power Applications	179
8.5	Conclusion	180
	References	181
9	Ion Induction Accelerators	185
	John J. Barnard and Kazuhiko Horioka	
9.1	Ion Sources and Injectors	185

9.1.1	Physics of High Current-Density Ion Sources	186
9.1.2	Ion Sources	194
9.1.3	Example Injectors	197
9.2	Longitudinal Beam Dynamics	200
9.2.1	Fluid Equation Approach	200
9.2.2	“g-Factor” Descriptions of E_z	201
9.2.3	Rarefaction Waves	202
9.2.4	“Ear Fields”	204
9.2.5	Longitudinal Waves	205
9.2.6	Longitudinal Instability	206
9.2.7	Effects of Capacitance on Longitudinal Instability	208
9.3	Transverse Dynamics Issues	210
	References	211
10	Applications of Ion Induction Accelerators	215
	John J. Barnard and Richard J. Briggs	
10.1	Driver for Heavy Ion Fusion (HIF)	215
10.1.1	Requirements Set by Target Physics	216
10.1.2	Final Focus Limits	217
10.1.3	Accelerator Architectures for Inertial Fusion Energy	219
10.1.4	Induction Acceleration and Energy Loss Mechanisms	222
10.1.5	Scaling of the Focusing Systems	224
10.1.6	Accelerator Scaling with Charge-to-Mass Ratio	227
10.1.7	Multi-Beam Linac with Quadrupole Focusing	228
10.1.8	Modular Drivers	230
10.1.9	Recirculator	232
10.1.10	Beam Manipulations	233
10.2	Other Applications of Ion Induction Accelerators	235
10.2.1	High Energy Density Physics and Warm Dense Matter Physics	235
10.2.2	Neutron Spallation Source	243
	References	244
11	Induction Synchrotron	249
	Ken Takayama	
11.1	Principle of Induction Synchrotron	249
11.1.1	Review of Phase Dynamics in an RF Synchrotron	251
11.1.2	Phase Dynamics in the Induction Synchrotron	254
11.2	Beam Handling	257
11.2.1	Beam Injection	258
11.2.2	Beam Stacking and Super-Bunch Formation	261
11.2.3	Transition Crossing	261

- 11.3 Induction Devices for an Induction Synchrotron 263
 - 11.3.1 Equivalent Circuit Model 264
 - 11.3.2 Induction Cell 266
 - 11.3.3 Switching Power Supply (Power Modulator) 269
- 11.4 Proof of Principle Experiment 273
 - 11.4.1 Beam–Cell Interaction: Beam Loading 273
 - 11.4.2 Scenario of Proof of Principle Experiment 275
 - 11.4.3 Induction Acceleration of an RF Bunch 276
 - 11.4.4 Confinement by Induction Barrier Voltages 279
 - 11.4.5 Induction Acceleration of a Trapped Barrier Bunch –
Full Demonstration of the Induction Synchrotron 279
- 11.5 Perspective 283
- References 284

- 12 Applications of Induction Synchrotrons 287**
Ken Takayama
 - 12.1 Typical Accelerator Complex Capable of Employing
the Induction Synchrotron Scheme 287
 - 12.2 Hybrid Synchrotrons 287
 - 12.2.1 Quasi-adiabatic Focusing-Free Transition Crossing 288
 - 12.3 Super-Bunch Hadron Colliders 291
 - 12.3.1 Introduction 291
 - 12.3.2 Contrast of Coasting Beam, RF Bunch Collider,
and Super-Bunch Colliders 291
 - 12.3.3 Generation of the Super-Bunch 293
 - 12.3.4 Luminosity 295
 - 12.3.5 Beam–Beam Effects and Crossing Geometry 300
 - 12.3.6 Typical Super-Bunch Collider’s Parameters 304
 - 12.3.7 Beam Physics Issues for the Super-Bunch
Hadron Collider 305
 - 12.4 All-Ion Accelerator – An Injector-Free
Induction Synchrotron 316
 - 12.4.1 Introduction 316
 - 12.4.2 Concept 319
 - 12.4.3 Digital Acceleration and Switching Frequency 320
 - 12.4.4 Longitudinal Confinement 322
 - 12.4.5 Stacking and Beam Handling Through
the Acceleration 322
 - 12.4.6 Transverse Focusing 323
 - 12.4.7 Space Charge Limited Ion-Beam Intensity 325
 - 12.4.8 Vacuum 325
 - 12.4.9 Ion Source and Injector 326
 - 12.4.10 Summary 327
 - References 327

- Index 331**