COMPACT SYNCHROTRON LIGHT SOURCES

This page is intentionally left blank

Ernst Wehreter

BESSY, Berlin, Germany

COMPACT SYNCHROTRON LIGHT SOURCES

World Scientific

Singapore • New Jersey • London • Hong Kong

Published by

World Scientific Publishing Co. Pte. Ltd.

P O Box 128, Farrer Road, Singapore 912805

USA office: Suite 1B, 1060 Main Street, River Edge, NJ 07661

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

Library of Congress Cataloging-in-Publication Data

Weihreter, Ernst.

Compact synchrotron light sources / Ernst Weihreter.

p. cm. -- (Series on synchrotron radiation techniques and applications : vol. 3)

Includes bibliographical references and index.

ISBN 9810224591

I. Synchrotron radiation sources. I. Title. II. Series.

QC793.5.E622W4 1996

539.7'35--dc20

96-22404

CIP

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

Copyright © 1996 by World Scientific Publishing Co. Pte. Ltd.

All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

This book is printed on acid-free paper.

Printed in Singapore by Uto-Print

To my father Max

This page is intentionally left blank

PREFACE

The development of compact synchrotron radiation sources is part of the growing effort of the scientific community to transfer achievements from fundamental research emerging from human curiosity to applications of technical and economical interest. As a particular characteristic of this century, these efforts have evolved into a race with shorter and shorter time intervals between milestones. It is a privilege to participate in this race as an actor and it is fun to follow this game as an observer, in spite of the risk for both to eventually get out of breath.

The high speed of research and development not only governs the mainstream of technology but also influences smaller fields. In this way the last ten years have given birth to more than a dozen development projects for compact storage rings with the aim to provide synchrotron radiation for applications outside the realm of basic research.

A direct consequence of the fast development speed is the lack of comprehensive and easily accessible technical information. Most of the material published on compact synchrotron light sources is scattered in numerous conference contributions and internal reports written by scientists and engineers working in accelerator laboratories and (so far to a lesser extend) in companies all over the world. The present volume is an attempt to help improve the situation in this field by providing an introduction, a description of the state of the art, a comprehensive collection of important design formula (often in practical units), and a reference book for physicists, engineers, and managers who are interested in the construction and operation of compact synchrotron radiation sources.

Selection of the material was guided by the aim to concentrate on the those aspects which are specific for compact storage rings omitting all topics which are part of the canonical subjects of accelerator physics and technology. This is more than justified, since several excellent textbooks became available in recent years, covering the fundamentals of circular accelerators such as linear particle optics, nonlinear effects, and beam instabilities.

This book grew out from many years of development work at BESSY related with COSY as well as from a number of articles and lecture notes for accelerator physics courses organized by the CERN Accelerator School, the Center for Theoretical Physics in Trieste, the Nato Advanced Study Institute, and the Synchrotron Radiation Research Center in Taiwan.

The author has profited enormously from the experience and help of his colleagues at BESSY and from many discussions with colleagues and friends throughout the accelerator community. It is not possible to mention them all.

My special thanks go to all who contributed in the design, construction, and commissioning of the compact storage ring COSY. It was their dedication which made this project an exciting adventure and an important step in the development of compact synchrotron light sources in spite of the problems we had to face on our way. I want to thank particularly Dr. Gottfried Mülhaupt, who initiated the COSY project, for his guidance in the early years of my professional life in the accelerator field, Dr. Wolf-Dieter Klotz, and Dr. Rudolf Maier for their help and continuous exchange of ideas. Many thanks go to Ms. Nikoline Hansen, and Ms. Stine Mallwitz for typesetting the manuscript, to Ms. Bärbel Bauda, and Mr. Knuth Seliger for the preparation of many of the drawings, and to Dr. Gode Wüstefeld and Dr. Shaukat Khan for careful proof reading of the text and for the suggestion of many improvements.

Ernst Weihreter,

December 1995

CONTENTS

Preface	vii
1. INTRODUCTION	1
1.1 Evolution of synchrotron light sources	3
2. POTENTIAL APPLICATIONS FOR COMPACT SOURCES	7
2.1 X-ray lithography	8
2.1.1 Source parameter considerations	12
2.2 Micromachining: The LIGA-process	14
2.2.1 Parameters for a LIGA source	17
2.3 Total reflection X-ray fluorescence analysis	18
2.4 Synchrotron light induced etching	21
2.5 Digital subtraction angiography	22
3. BASIC DESIGN CONSIDERATIONS FOR COMPACT STORAGE RING	27
3.1 Basic properties of synchrotron radiation	27
3.1.1 Radiation characteristics	27
3.1.2 Insertion devices	31
3.1.2.1 Wavelength shifters	31
3.1.2.2 Wigglers and undulators	32
3.2 Compactness and cost efficiency	34
3.3 Conventional vs superconducting bending magnets	35
3.4 Flux vs brightness	37
3.5 Beamsize and emittance	39
3.5.1 Equilibrium parameters	40
3.5.2 Minimization of emittance	42
3.6 Methods for large area exposure	43
3.6.1 Mechanical and optical scanning	43
3.6.2 Electron beam wobbling	45
4. ELECTRON OPTICAL CONCEPTS FOR COMPACT RINGS	49
4.1 Conventional lattices with iron magnets	49
4.1.1 The FODO-lattice	50

4.1.2	The triplet achromat lattice	51
4.1.3	The Chasman-Green lattice	52
4.1.4	The double bend achromat lattice	53
4.1.5	The triple bend achromat lattice	54
4.1.6	The double DBA lattice	55
4.2	Compact ring lattices with superconducting magnets	55
4.2.1	Weak focusing circular symmetric rings	57
4.2.2	Racetrack rings	60
4.2.3	Stability limit for a weak focusing racetrack configuration	61
4.2.4	Strong focusing racetrack rings	62
4.2.5	Racetrack storage ring combined with a racetrack microtron	67
4.2.6	Lattices with higher symmetry	69
4.2.7	Hybrid rings	71
4.2.7.1	Wiggler dominated compact rings	71
4.2.7.2	Rings with superconducting and conventional dipoles	72
4.3	The effect of non-isomagnetic fields	73
4.3.1	Calculation of the reference orbit	74
4.3.2	Linear optics with non-isomagnetic fields	76
5.	INJECTION AT LOW ENERGY	79
5.1	Preaccelerators	80
5.2	Injection methods	81
5.2.1	Singleturn injection	81
5.2.2	Multiturn injection	83
5.2.3	Beam accumulation at low energy	84
5.2.4	Betatron injection	88
5.2.5	Resonance injection	90
5.3	Beam lifetime	92
5.3.1	Lifetime limitation by beam-gas interaction	92
5.3.2	Touschek lifetime	95
5.3.3	Intrabeam scattering	98
5.4	Ion trapping and clearing	100
5.4.1	Ion generation	101
5.4.2	Ion trapping and stability	103

5.4.3	Pressure increase	107
5.4.4	Incoherent tune shift	108
5.4.5	Clearing of ions with dc-voltage	109
5.4.6	Beam shaking	112
5.4.7	Clearing with a filling gap	114

6. SUPERCONDUCTING BENDING MAGNETS FOR COMPACT RINGS

6.1	Basic concepts	117
6.1.1	Superferric magnets	118
6.1.2	$\cos\phi$ -type dipoles	119
6.1.3	Iron-free magnets	119
6.1.4	Iron magnets for fields above 2 T	121
6.1.5	Cold bore or warm bore?	123
6.2	Field calculations	126
6.2.1	'Air-core'-magnets	126
6.2.1.1	Field of a straight coil element with rectangular cross-section	127
6.2.1.2	Field of a circular coil element	128
6.2.2	Generation of multipole fields	130
6.2.3	Magnetic forces	133
6.3	Technical considerations	134
6.3.1	Superconducting cables	134
6.3.2	Quench protection	137
6.3.3	Cryogenic environment	139
6.3.4	Stainless steel at low temperatures	141
6.4	Examples	144
6.4.1	The 180° COSY dipoles	144
6.4.2	Concept of a 90° dipole for KSSQ	150
6.5	Field measurements	153

7. SURVEY OF COMPACT SYNCHROTRON LIGHT SOURCES

7.1	Examples of superconducting rings	157
7.1.1	AURORA	161
7.1.2	COSY	165

7.1.3	HELIOS	168
7.1.4	NIJI III	172
7.1.5	Super-ALIS	174
7.1.6	SXLS	176
7.1.7	MELCO	178
7.2	Compact source development in Russia	180
7.3	Examples of conventional magnet rings	185
7.3.1	AURORA-2	185
7.3.2	LUNA	188
7.3.3	NAR	190
7.3.4	SORTEC	191
7.4	Compact source projects for digital k-edge subtraction angiography	195
References		199
Address List		211
Index		213