

MEGAGAUSS PHYSICS
AND TECHNOLOGY

MEGAGAUSS PHYSICS AND TECHNOLOGY

Edited by

Peter J. Turchi

*Naval Research Laboratory
Washington, D. C.*

PLENUM PRESS · NEW YORK AND LONDON

Library of Congress Cataloging in Publication Data

International Conference on Megagauss Magnetic Field Generation and Related Topics, 2d, Washington, D.C., 1979.
Megagauss physics and technology.

Includes index.

1. Magnetic fields—Congresses. 2. Magnetics—Congresses. I. Turchi, Peter J. II. Title.
QC754.2.M3I57 1979 538 80-16385
ISBN-13: 978-1-4684-1050-1 e-ISBN-13: 978-1-4684-1048-8
DOI: 10.1007/978-1-4684-1048-8

Proceedings of the Second International Conference on Megagauss
Magnetic Field Generation and Related Topics, held in
Washington, D.C., May 30–June 1, 1979.

© 1980 Plenum Press, New York
Softcover reprint of the hardcover 1st edition 1980
A Division of Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted,
in any form or by any means, electronic, mechanical, photocopying, microfilming,
recording, or otherwise, without written permission from the Publisher

EDITOR'S PREFACE

The generation and use of megagauss magnetic fields have been subjects of research and development in laboratories around the world for over a quarter of a century. Research goals have included the development of compact, short-pulse, electrical power sources and the production of ultrahigh magnetic field strengths over significant experimental volumes. Energies measured in megajoules, currents in megamperes and timescales of microseconds are not uncommon in such work. Phase changes, insulator breakdowns, and local destruction of the apparatus are also frequently encountered. Some efforts have involved the use of high explosive systems, developing methodologies rather distinct from those of a normal physics laboratory. Manipulation of magnetic flux to exchange energy between high speed, electrically conducting flows and high strength electromagnetic fields remains, of course, a basic interaction of classical physics.

The remoteness of the necessary experimental sites (at least in many instances) and the various national concerns for security of defense-related research have often limited the flow of information between investigators of separate organizations, working in common areas of technical concern. Occasionally, however, it has been possible for the community of scientists and engineers engaged in work on high magnetic fields and related high energy density systems to gather together and exchange results and plans, successes and failures. The first such international gathering was in 1965 at the Conference on Megagauss Magnetic Field Generation by Explosives and Related Experiments, Frascati, Italy. The proceedings of the conference were published by Euratom (EUR 2750.e) and have served as a useful reference for many years.

The present volume, *Megagauss Physics and Technology*, is based on papers given at the Second International Conference on Megagauss Magnetic Field Generation and Related Topics, held in Washington, D.C., 30 May-1 June 1979. It may be hoped that this work will also be a useful reference. Topics at the Conference ranged from magnetic flux-compression generator design to applications of high magnetic field techniques for controlled thermonuclear fusion, and included discussions of diagnostic methods, accelerator concepts, switching, and theoretical modeling. Some topics are of passing or recurrent interest, while others are more fundamental or utilitarian in nature.

As might be expected, the sixty technical papers presented here have many points of contact and overlap with each other. Often, reports of both theoretical and experimental work on several subjects are included within a single paper. The arrangement of papers has, therefore, generally followed the

order of presentation at the Conference, thereby at least preserving some mnemonic advantage for the Conference participants. It should be noted, however, that nine Soviet papers which were synopized at different times during the Conference are collected at the end of the volume since closely-related aspects of research efforts at two laboratories are reviewed in these papers. (Careful comparison with the actual program of the Conference would reveal to those so inclined that there are some other additions, omissions, and rearrangements, due primarily to limited editorial resources relative to nonsubmission of papers and forms, inadequate figures, or late arrivals.)

The editorial work involved two close screenings of the re-typed manuscripts to eliminate typographical errors, and to provide occasional adjustments of language. In the latter regard, English translations of technical expressions have generally been left in the form supplied by the authors, since special points of view may be indicated by language usage. Comparison with other literature is also facilitated by this policy. Some phrases, however, typically involving less subtle features such as suffixes, have been adjusted.

At various places, omissions in the text have occurred without a reasonably certain clue as to the author's intention. In such circumstances, since the authors have not been available for ready consultation during the editorial process, a best estimate is provided, with the notation [ed. est.]. Other notational policies are the use of italics for algebraic symbols, bold-face italics for vectors, parentheses for equation numbers, and brackets for reference numbers. No attempt has been made to verify the accuracy of the mathematics presented by various authors. Indeed, technical review was not provided (even though the editor had considerable reservations in some instances) and no endorsement of the scientific merit or validity of the reported efforts should be inferred by presentation in this volume. Much of the material, however, was discussed at the Conference itself and was thereby subjected to community review. Correction of significant errors (especially those introduced by the editorial process) can be attempted by contacting a member of the Organizing Committee of the Conference. An errata sheet for the volume may then be generated and distributed at a future date. A list of organizational mailing addresses has been provided for direct correspondence with the authors.

The Conference, known to its friends as Megagauss II, was possible due to the considerable contributions of the Organizing Committee and Sponsoring Organizations listed on the following page, and to the enthusiastic response of the Conference participants and authors. Special appreciation is due to Ms. Francine Rosenberg who served as the Conference Secretary and handled the great many details involved in preparing and carrying out the tasks of the Conference, thereby ensuring its success.

The text of the present volume was prepared through the gracious efforts of Mrs. Dora Wilbanks and her staff using the computer-assisted composition system at the Naval Research Laboratory. The considerable tasks of arranging the text by hand, correction and re-setting were accomplished by the dedicated effort of Mrs. Judy Kogok. Errors and delays in publication of this volume are due to the editor:

P. J. Turchi

**SECOND INTERNATIONAL CONFERENCE ON
MEGAGAUSS MAGNETIC FIELD GENERATION
AND RELATED TOPICS**

29 May - 1 June 1979

Washington, D.C.

ORGANIZING COMMITTEE:

M. Cowan
Sandia Laboratories,
Albuquerque

C. M. Fowler
Los Alamos Scientific
Laboratory

J. W. Shearer
Lawrence Livermore
Laboratory

G. A. Shvetsov
Institute of Hydrodynamics,
Novosibirsk

V. M. Titov
Institute of Hydrodynamics,
Novosibirsk

P. J. Turchi (Chairman)
Naval Research Laboratory
Washington, D.C.

SPONSORING ORGANIZATIONS:

Institute of Hydrodynamics, Novosibirsk

Lawrence Livermore Laboratory

Los Alamos Scientific Laboratory

Naval Research Laboratory

Sandia Laboratories

Air Force Office of Scientific Research

Office of Naval Research

Office of Fusion Energy, Department of Energy

Office of Inertial Fusion, Department of Energy

CONTENTS

Experimental Techniques in Ultrahigh Magnetic Field Generation

Pulsed Magnetic Field Generators and Their Practical Applications	1
Fritz Herlach	
Production and Measurements of Megagauss Magnetic Fields in Single-Turn Coils	27
N.N. Gennadiev, V.F. Demichev, and P.A. Levit	
Measurement of Pulsed Magnetic Fields Produced by Flux Compression in Imploding Liners	37
R.A. Nuttelman, J.H. Degnan, G.F. Kiuttu, R.E. Reinovsky, and W.L. Baker	
TOFS-A Timing Optical Fiber System	47
Dan L. Davis	
Test Bench for Operation with Great Explosive Charges Under Laboratory Conditions	55
A.F. Demtshuk, V.V. Poljudov, V.M. Titov, and G.A. Shvetsov	
Conductors and Insulators at High Energy Densities and Speeds	
High-Energy Electric Pulse Generation by Cumulative Explosion	61
G.A. Shvetsov and V.M. Titov	
Explosive Plasma Source Experiment	77
Dennis W. Baum and W. Lee Shimmin	
Electrophysical Properties of Detonation Products of Condensed Explosives	89
A.P. Ershov, L.A. Lukjantshikov, Ju. V. Rjabinin, and P.I. Zubkov	
Xenon Shock Waves Driven by High Magnetic Fields	99
J.W. Shearer, J.W. Beasley, A. Reyenga, and D. Steinberg	
Extinguishing of the Electric Arc Compressed by Shock Waves	111
L.A. Lukjantshikov, K.A. Ten, and P.I. Zubkov	
Design and Analysis of Isentropic Compression Experiments	117
R.S. Hawke	

Effects of Metallurgical Microstructure of Armatures on Compressed Magnetic Field Generators	131
A.E. Binder and T.V. Nordstrom	
Shock-Induced Electrical Switching in Polymeric Films	147
R.A. Graham	
Generation of Ultrahigh Magnetic Fields by Small-Scale Single-Shot Experiments	151
Y. Nakagawa, S.M. Miura, T. Goto, and Y. Syono	
Modeling of Magnetodynamic Systems	
Small Helical Flux Compression Amplifiers	163
J.E. Gover, O.M. Stuetzer, and J.L. Johnson	
Energy Capabilities and Magnetic Flux Losses in "Bellows"-Type Explosive Generators	181
E.I. Bitshenkov and V.A. Lobanov	
COMAG-III: A 2-D MHD Code for Helical CMF Generators	193
J.M. McGlaun,, S.L. Thompson, and J.R. Freeman	
Numerical Studies of Helical CMF Generators	205
J.R. Freeman, J.M. McGlaun, S.L. Thompson, and E.C. Cnare	
MHD Phenomena at High Magnetic Reynolds Number	219
S.P. Gill	
Plasma Crowbars in Cylindrical Flux Compression Experiments	231
L.J. Suter	
Magnetic Flux Compression by Expanding Plasma Armatures	241
T.P. Wright, L. Baker, M.Cowan, and J.R. Freeman	
An Equivalent Circuit Model for a Solenoidal Compressed Magnetic Field Generator	249
M. Jones	
A Finite-Element Model of Compressed Magnetic Field Generators	265
T.J. Tucker	
Advanced Pulsed Power Topics	
Pulse Transformer Operation in Megagauss Fields	275
C.M. Fowler, R.S. Caird, D.J. Erickson, B.L. Freeman, and W.B. Garn	
Magnetic Propulsion for a Hypervelocity Launcher	287
J.P. Barber, R.A. Marshall, and S. Rashleigh	

Magnetic Propulsion Railguns: Their Design and Capabilities	297
R.S. Hawke and J.K. Scudder	
Shiva X-Ray Source Experiments	313
R.E. Reinovsky, J.H. Degnan, G.F. Kiuttu, R.A. Nuttelman, and W.L. Baker	
Numerical Simulation of the Effects of an Injected B_z Field on an Imploding Hollow Plasma Liner	327
T.W. Hussey, D.A. Kloc, C.W. Beason, and N.F. Roderick	
Inductively Driven Imploding Plasma System for X-Ray Generation	337
D.L. Smith, R.P. Henderson, and R.E. Reinovsky	
A Very Fast Electromagnetically Operated Circuit Breaker	351
P. D’Hommee-Caupers, C. Rioux, F. Rioux-Damidau, and C. Jablon	
Fast Opening Switches Carrying Multimegampere Currents	361
D.J. Steinberg and J.W. Shearer	
Imploding Liner Systems for Fusion	
Review of the NRL Liner Implosion Program	375
P.J. Turchi, A.L. Cooper, R.D. Ford, D.J. Jenkins, and R.L. Burton	
On Efficiency of Two-Step Energy Transformation in a System with Inductive Storage for MCG Magnetic Field Production	387
E.A. Azizov, V.P. Bazilevski, Ju. A. Kareev, and I.V. Kochurov	
Results from the Los Alamos Fast Liner Experiment	391
A.R. Sherwood, E.L. Cantrell, C.A. Ekdahl, I. Henins, H.W. Hoida, T.R. Jarboe, P.L. Klingner, R.C. Malone, J. Marshall, and G.A. Sawyer	
Liner Thermonuclear Systems with Superhigh Magnetic Field and $\beta > 1$	399
Ju.A. Kareev, I.K. Konkashbaev, and L.B. Nikandrov	
Adiabatic Compression of 3-D Plasma Magnetic Field Configuration	403
W. Grossman and J. Saltzman	
Numerical Simulation of Dynamics of Quasispherical Metallic Liner	415
V.M. Goloviznin, R.Kh. Kurtmullaev, V.N. Semenov, V.A. Gasilov, A.P. Favorsky, and M.Yu. Shashkov	
A Conceptual Design for an Imploding-Liner Fusion Reactor	425
A.E. Robson	
Stabilization Concepts of Imploding Liquid Metal Liner	437
Y. Itoh and Y. Fujii-E	

Modeling of LINUS-Type Stabilized Liner Implosions	447
A.L. Cooper, J.M. Pierre, P.J. Turchi, J.P. Boris, and R.L. Burton	

Megagauss Field Generation

Megagauss Fields Produced with Small Explosive Charges	461
R.S. Caird, J.H. Brownell, D.J. Erickson, C.M. Fowler, B.L. Freeman, and T. Oliphant	
Investigation of Capabilities of Magneto-Cumulative Megagauss Magnetic Field Generation	471
E.I. Bitshenkov, V.A. Lobanov, V.I. Telenkov, and A.M. Trubatshev	
Production of Megagauss Fields by Compression of Magnetic Flux by a Metallic Liner	479
A.M. Andrianov, Yu.A. Alekseev, V.L. Baryshev, V. I. Vasil'ev, M.N. Kazeev, and V.V. Kisula	
Megagauss Magnetic Field Production in Small Volumes	485
U.N. Botcharov, A.I. Krutchinin, S.I. Krivosheev, A.N. Chetchel, and G.A. Shneerson	
On a Novel Scheme for the Generation of Megagauss Fields	497
O.K. Mawardi	
Superhigh Magnetic Field Generation by a Cumulating Liner and Magnetopressed Discharge	505
S.G. Alikhanov and V.P. Novikov	
Experimental and Computational Study of Axial Magnetic Field Compression by Cylindrical Plasma Liners	511
J.H. Degnan, R.A. Nuttelman, G.F. Kiuttu, R.E. Reinovsky, and W.L. Baker	

Applications of Ultrahigh Magnetic Field Techniques

Abstract of Report of the Panel on High Magnetic Field Research and Facilities	519
S.P. Keller	
Design, Performance and Use of a Near Megagauss Pulsed Machine	521
N.T. Olson, J. Bandas, and A.C. Kolb	
Experimental Research on Explosive-Driven Magnetic Generator Performance with Resistive-Inductive Load	527
B.D. Khristoforov, I.I. Divnov, N.I. Zotov, and O.P. Karpov	

Megagauss Fields and Current Pattern in Focussed Discharges	533
W.H. Bostick, V. Nardi, J. Feugeas, L. Grunberger, W. Prior, C. Cortese, F. Mezzetti, and A. Pedrielli	
Application of Strong Magnetic Fields for the Acceleration of Charged Particles	543
V.S. Panasjuk, A.A. Sokolov, and B.M. Stepanov	
Magnetocumulative Generator Systems	
Magnetic Cumulation Generator Parameters and Means to Improve Them	557
A.I. Pavlovskii, R.Z. Lyudaev, V.A. Zolotov, A.S. Seryoghin, A.S. Yuryzhev, M.M. Kharlamov, A.M. Shuvalov, V.Ye. Gurin, G.M. Spirov, and B.S. Makaev	
A Multiwire Helical Magnetic Cumulation Generator	585
A.I. Pavlovskii, R.Z. Lyudaev, L.I. Sel'chenkov, A.S. Seryoghin, V.A. Zolotov, A.S. Yuryzhev, O.I. Zenkov, V.Ye. Gurin, A.S. Boriskin, and V.F. Basmanov	
Formation and Transmission of Magnetic Cumulation Generators Electromagnetic Energy Pulses	595
A.I. Pavlovskii, R.Z. Lyudaev, A.S. Kravchenko, V.A. Vasyukov, L.N. Pljashkevich, A.M. Shuvalov, A.S. Russkov, V.Ye. Gurin, B.A. Boyko, and V.A. Zolotov	
Transformer Energy Output Magnetic Cumulation Generators	611
A.I. Pavlovskii, R.Z. Lyudaev, L.N. Pljashkevich, A.M. Shuvalov, A.S. Kravchenko, Yu.I. Plyushchev, D.I. Zenkov, V.F. Bukharov, V.Ye. Gurin, and V.A. Vasyukov	
Reproducible Generation of Multimegagauss Magnetic Fields	627
A.I. Pavlovskii, N.P. Kolokolchikov, O.M. Tatsenko, A.I. Bykov, M.I. Dolotenko, and A.A. Karpikov	
High Inductance Explosive Magnetic Generators with High Energy Multiplication	641
V.K. Chernyshev, E.J. Zharinov, V.A. Demidov, and S.A. Kazakov	
Generation of the Magnetic Flux by Multicascade Capture	651
V.K. Chernyshev and V.A. Davydov	
Ultimate Capacities of Transformer Method of Energy Transfer from Explosive Magnetic Generator to Inductive Load	657
V.K. Chernyshev and V.A. Davydov	
Study of Basic Regularities of Formation of Multi-MA-Current Pulses with Short Risetime by EMG Circuit Interruption	663
V.K. Chernyshev, G.S. Volkov, V.A. Ivanov, and V.V. Vakrushev	

Addresses of Author Organizations 677

Author Index 679

Subject Index 683