Fourth Edition

ENGINEERING TRIBOLOGY

Gwidon W. Stachowiak
Andrew W. Batchelor

B
H

ENGINEERING TRIBOLOGY

FOURTH EDITION

Gwidon W. Stachowiak
Department of Mechanical Engineering
Curtin University
Perth, Australia

Andrew W. Batchelor
Saudi Aramco
Dhahran, Saudi Arabia

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Butterworth-Heinemann is an imprint of Elsevier

Butterworth-Heinemann is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK
225 Wyman Street, Waltham, MA 02451, USA

First edition 1993

Copyright © 2014 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the publisher.

Permissions may be sought directly from Elsevier's Science & Technology Rights Department in Oxford, UK: phone (+44) (0) 1865 843830; fax (+44) (0) 1865 853333; email: permissions@elsevier.com. Alternatively you can submit your request online by visiting the Elsevier web site at http://elsevier.com/locate/permissions, and selecting *Obtaining permission to use Elsevier material.*

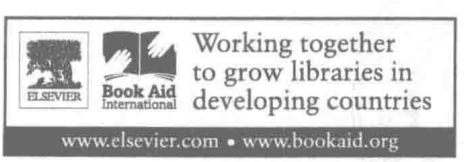
Notice
No responsibility is assumed by the publisher for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. Because of rapid advances in the medical sciences, in particular, independent verification of diagnoses and drug dosages should be made.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-810031-8

For information on all Butterworth-Heinemann publications
visit our website at books.elsevier.com



Transferred to Digital Printing in 2016

ENGINEERING TRIBOLOGY

此为试读,需要完整PDF请访问: www.ertongbook.com

To the most important persons in our lives
Grazyna Stachowiak
Gwidon (Jr.) Stachowiak
and
Valli M. Batchelor
Diana, Vicky & Vincent Batchelor

PREFACE

Some 20 years ago we decided to write a textbook on 'Engineering Tribology' and to our pleasant surprise a publisher supported the idea. Students had requested a book suitable for the study of tribology and the existing textbooks were either too specialized or too literal in content. Many books provided exhaustive reviews of friction and wear data, while others contained detailed descriptions of the lubrication and wear problems occurring in machinery. A book which presents the concepts of tribology in terms useful to engineering students and engineers was, however, lacking.

In the books published at the time, the basic models of friction and wear were not explained adequately. As a result, more sophisticated concepts could not be well understood. The interdisciplinary nature of tribology, with knowledge drawn from different disciplines such as mechanical engineering, materials science, chemistry and physics, leads to a general tendency for the chemist to describe in detail, for example, lubricant additives, the mechanical engineer to discuss, for example, pad or journal bearings and so on, with no overall guide to the subject. In this book, the interaction between these different fields of knowledge to achieve the final result, the control of friction and wear, is emphasized. The interdisciplinary view of tribology was largely developed by Professor Alastair Cameron about four decades ago and this approach has proved to be the most successful way of analysing friction and wear problems.

In many cases tribology is viewed as an inaccessible subject which does not produce useful answers. In this 'Engineering Tribology' book we try to redress this problem. Rutherford's maxim, that 'any good scientific theory is explainable to the average barmaid', is applied in this book with various concepts explained in the simplest possible terms with supporting illustrations.

Now it is time to write the 4th edition with amendments in the same style as the earlier versions. The previous editions were received very favourably by the reviewers and especially by the students.

In the 4th edition of 'Engineering Tribology' we aim to update the contents of the third edition while maintaining its style. In this edition, a number of extra topics have been included to make the book more comprehensive and up to date. The listings of literature citations have been extended to include recent findings from tribology research. Extra diagrams have also been included where it was found that the readability and comprehension of the original text could be improved. Computer programs used in the numerical analysis have been upgraded to the current version of MATLAB. A new computer program 'SPIKE' for calculating the grit particle angularity has also been added. To provide opportunities for active learning, a series of revision questions are provided at the end of each chapter. This should be helpful in assessing the understanding for both students and lecturers. Despite all these changes, the purpose of writing 'Engineering Tribology' remains

the same, i.e., to provide a reader-friendly and comprehensive introduction to the subject of tribology and its implications for engineering.

This edition, like the previous editions, is intended for final year under-graduate and post-graduate students in mechanical engineering and professional engineers. The subject matter of the book is also relevant to materials engineering, applied chemistry, physics and bioengineering courses.

Gwidon W. Stachowiak

Andrew W. Batchelor

ACKNOWLEDGEMENTS

Any book depends on the efforts of many different people and this book is no exception. Firstly, we would like to thank Dr Grazyna Stachowiak for very detailed research, review of technical material, proof-reading, many constructive discussions, SEM micrographs and preparation of index; Dr Mike Hamblin for the concept development of the Spike Parameter Quadratic Fit and Dr Marcin Wolski for converting it into the MATLAB; Professor Motohiro Kaneta for useful comments on elastohydrodynamic lubrication; Professor Emily Brodsky from the University of California Santa Cruz and Dr Amir Sagy from Geological Survey of Israel for the photo of the fault line (Figure 10.25) and a helpful discussion on rock faults; Gosia Wlodarczak-Sarnecka for the design of the book cover; Longin Sarnecki for the cover photo. We would like to thank the School of Mechanical and Chemical Engineering, University of Western Australia, and the Department of Mechanical Engineering, Curtin University in Western Australia for their help during the preparation of the manuscript. The support of Saudi Aramco is also gratefully acknowledged.

Finally, we would like to thank the following publishers for granting us permission to reproduce the figures listed below:

Figure 9.7: Society of Tribologists and Lubrication Engineers. From Tribology Transactions, Vol. 31, 1988, pp. 214-227.

Figures 13.5 and 13.11: Japanese Society of Tribologists. From Journal of Japan Society of Lubrication Engineers, Vol. 31, 1986, pp. 883-888 and Vol. 28, 1983, pp. 53-56, respectively.

Figures 14.2 and 15.2: Royal Society of London. From Proceedings of the Royal Society of London, Vol. 394, 1984, pp. 161-181 and Vol. 230, 1955, pp. 531-548, respectively.

Figure 16.6: The American Society of Mechanical Engineers. From Transactions of the ASME, Journal of Lubrication Technology, Vol. 101, 1979, pp. 212-219.

Figures 11.41 and 16.22 were previously published in Wear, Vol. 113, 1986, pp. 305-322 and Vol. 17, 1971, pp. 301-312, respectively.

此为试读,需要完整PDF请访问: www.ertongbook.com

CONTENTS

PREFACE xxvii

ACKNOWLEDGEMENTS xxix

1 INTRODUCTION 1
- 1.1 Background 1
- 1.2 Meaning of tribology 2
- Lubrication 3
- Wear 5
- 1.3 Cost of friction and wear 5
- 1.4 Summary 9
- Revision questions 9
- References 10

2 PHYSICAL PROPERTIES OF LUBRICANTS 11
- 2.1 Introduction 11
- 2.2 Oil viscosity 11
- Dynamic viscosity 12
- Kinematic viscosity 13
- 2.3 Viscosity temperature relationship 13
- Viscosity-temperature equations 14
- Viscosity-temperature chart 14
- 2.4 Viscosity index 15
- 2.5 Viscosity pressure relationship 17
- 2.6 Viscosity-shear rate relationship 22
- Pseudoplastic behavior 22
- Thixotropic behavior 24
- 2.7 Viscosity measurements 24
- Capillary viscometers 24
- Rotational viscometers 26
  - · Rotating cylinder viscometer 27
  - · Cone on plate viscometer 29
- Other viscometers 29
- 2.8 Viscosity of mixtures 31

2.9	Oil viscosity classification	31
	SAE viscosity classification	31
	ISO viscosity classification	33
2.10	Lubricant density and specific gravity	33
2.11	Thermal properties of lubricants	34
	Specific heat	34
	Thermal conductivity	35
	Thermal diffusivity	35
2.12	Temperature characteristics of lubricants	35
	Pour point and cloud point	36
	Flash point and fire point	37
	Volatility and evaporation	37
	Oxidation stability	38
	Thermal stability	39
2.13	Other lubricant characteristics	40
	Surface tension	40
	Neutralization number	43
	Carbon residue	43
2.14	Optical properties of lubricants	43
	Refractive index	43
2.15	Additive compatibility and solubility	44
	Additive compatibility	44
	Additive solubility	44
2.16	Lubricant impurities and contaminants	44
	Water content	44
	Sulphur content	45
	Ash content	45
	Chlorine content	45
2.17	Solubility of gases in oils	45
2.18	Summary	48
Revision questions		48
References		49

3	**LUBRICANTS AND THEIR COMPOSITION**	**51**
3.1	Introduction	51
3.2	Mineral oils	52
	Sources of mineral oils	52
	Manufacture of mineral oils	54
	Types of mineral oils	56

- Chemical forms 56
- Sulphur content 57
- Viscosity 57

3.3 Synthetic oils 57
Manufacturing of synthetic oils 58
Hydrocarbon synthetic lubricants 59
- Polyalphaolefins 59
- Polyphenyl ethers 59
- Esters 60
- Cycloaliphatics 61
- Polyglycols 61

Silicon analogues of hydrocarbons 62
- Silicones 62
- Silahydrocarbons 62

Organohalogens 63
- Perfluoropolyethers 63
- Chlorofluorocarbons 63
- Chlorotrifluoroethylenes 64
- Perfluoropolyalkylethers 64

Cyclophosphazenes 64
3.4 New developments in synthetic lubricants 64
Ionic liquid lubricants 65
Mesogenic lubricants 66
3.5 Emulsions and aqueous lubricants 67
Manufacturing of emulsions 67
Characteristics 67
Applications 68
Polyelectrolyte lubricants 68
3.6 Greases 69
Manufacturing of greases 69
Composition 69
- Base oils 70
- Thickener 70
- Additives 71
- Fillers 71

Lubrication mechanism of greases 72
Grease characteristics 75
- Consistency of greases 75
- Mechanical stability 76

- Drop point 77
- Oxidation stability 78
- Thermal stability 79
- Evaporation loss 79
- Grease viscosity characteristics 79

Classification of greases 81
Grease compatibility 83
Degradation of greases 83

3.7 Lubricant additives 84
Wear and friction improvers 84
- Adsorption or boundary additives 85
- Antiwear additives 86
- Extreme-pressure additives 88

Nanoparticle additives 89
Anti-oxidants 89
- Oil oxidation 89
- Oxidation inhibitors 92

Corrosion control additives 95
Contamination control additives 95
Viscosity improvers 97
Pour point depressants 98
Foam inhibitors 98
Interference between additives 99

3.8 Summary 100
Revision questions 100
References 101

4 HYDRODYNAMIC LUBRICATION 105
4.1 Introduction 105
4.2 Reynolds equation 105
Simplifying assumptions 107
Equilibrium of an element 107
Continuity of flow in a column 111
Simplifications to the Reynolds equation 113
- Unidirectional velocity approximation 113
- Steady film thickness approximation 113
- Isoviscous approximation 114
- Infinitely long bearing approximation 114
- Narrow bearing approximation 115

Bearing parameters predicted from Reynolds equation 117
· Pressure distribution 117
· Load capacity 117
· Friction force 118
· Coefficient of friction 119
· Lubricant flow 119
Summary 119
4.3 Pad bearings 120
Infinite linear pad bearing 120
· Bearing geometry 120
· Pressure distribution 121
· Load capacity 123
· Friction force 124
· Coefficient of friction 127
· Lubricant flow rate 128
Infinite Rayleigh step bearing 129
Other wedge geometries of infinite pad bearings 132
· Tapered land wedge 132
· Parabolic wedge 133
· Parallel surface bearings 134
· Spiral groove bearing 135
Bearings with surface textures 136
Finite pad bearings 137
Pivoted pad bearing 139
Inlet boundary conditions in pad bearing analysis 141
4.4 Converging-diverging wedges 143
Bearing geometry 144
Pressure distribution 144
· Full-Sommerfeld boundary condition 146
· Half-Sommerfeld boundary condition 147
· Reynolds boundary condition 149
Load capacity 150
4.5 Journal bearings 152
Evaluation of the main parameters 152
· Bearing geometry 152
· Pressure distribution 154
· Load capacity 155
· Friction force 160
· Coefficient of friction 161

- Lubricant flow rate 163

Practical and operational aspects of journal bearings 165

- Lubricant supply 165
- Cavitation 169
- Journal bearings with movable pads 170
- Journal bearings incorporating a Rayleigh step 171
- Oil whirl or lubricant caused vibration 171
- Rotating load 174
- Tilted shafts 176
- Partial bearings 177
- Elastic deformation of the bearing 178
- Infinitely long approximation in journal bearings 178

4.6 Thermal effects in bearings 179

Heat transfer mechanisms in bearings 180

- Conduction 180
- Convection 181
- Conducted/convected heat ratio 181

Isoviscous thermal analysis of bearings 182

- Iterative method 183
- Constant flow method 184

Non-isoviscous thermal analysis of bearings with locally varying viscosity 185

Multiple regression in bearing analysis 186

Bearing inlet temperature and thermal interaction between pads of a Michell bearing 188

4.7 Limits of hydrodynamic lubrication 189

4.8 Hydrodynamic lubrication with non-Newtonian fluids 190

Turbulence and hydrodynamic lubrication 191

Hydrodynamic lubrication with non-Newtonian lubricants 192

Inertia effects in hydrodynamics 193

Compressible fluids 194

Compressible hydrodynamic lubrication in gas bearings 196

4.9 Reynolds equation for squeeze films 198

Pressure distribution 199

Load capacity 200

Squeeze time 201

Cavitation and squeeze films 202

Microscopic squeeze film effects between rough sliding surfaces 203

4.10 Porous bearings 203

4.11 Summary 204

此为试读,需要完整PDF请访问: www.ertongbook.com