Fluid Film Lubrication

Second Edition

Fluid film bearings are machine elements that should be studied within the broader context of tribology. The three subfields of tribology – friction, lubrication, and wear – are strongly interrelated. The last decade has witnessed significant advances in the area of fluid film lubrication and its applications, and this second edition offers a look at some of these advances. This edition adds to the fundamentals of fluid film lubrication a discourse on surface effects and the inclusion of treatment of flow with significant inertia within the section on turbulence. Basic ideas of the multigrid method are conveyed along with multilevel multi-integration in the treatment of elastohydrodynamic lubrication. The chapter on lubrication with non-Newtonian fluids discusses the impact of the so-named qualitative EHL. This chapter also contains a thorough discussion of blood as a lubricant, with a view of the application of lubrication theory to LVADs. New chapters have been included on ultra-thin films, both liquid and gaseous, and lubrication of articulating joints and their replacement. Some of the most recent literature is discussed.

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To my wife Mary for her continued encouragement

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Preface to the Second Edition

For the successful operation of mechanical devices, from spinning computer disks to automobiles to large electric generators of nuclear power stations, it is essential that the components that are destined to move relative to one another do so with low friction and rate of wear. This is made possible through appropriate design and utilization of fluid film bearings. Traditionally, fluid film lubrication was a purely mechanical subject, but with the emergence of bioengineering, the technology also finds application in lubricating artificial joints, contact lenses, and mechanical heart pumps, to name a few. In this second edition, I have tried to give a flavor of some of these advances. The contents of the first edition remain valid by and large, as they deal with the fundamentals that have changed little. Thus, this edition represents addition, rather than revision, of material. Chapter 2 is rewritten, however, to align it with a more complete discussion of constitutive theory. Chapter 3, the chapter covering thick-film lubrication, features a section on surface texturing; another section treats surface roughness in a more thorough manner. The chapter on turbulence includes the handling of flow with significant inertia. In the treatment of elastohydrodynamic lubrication, covered in Chapter 8, I tried to convey basic ideas of the multigrid method and touched on multilevel multi integration. The chapter on lubrication with non-Newtonian fluids discusses the "qualitative" EHL, and contains a discourse on lubrication with piezoviscous fluids, relative to the Reynolds equation. This chapter also comprises a thorough discussion of blood as lubricant, with a view to the application of lubrication theory to artificial organs. Chapters 12 and 13 are new. In the first of these, I concentrate on ultra-thin films, both liquid and gaseous. The chapter discusses and classifies recent research results and, particularly for gas films but also for liquid films, outlines design principles. The chapter closes with the listing of 92 up-to-date references. The last chapter, Biotribology, is devoted to lubrication of the hip joint. Its two principal sections discuss lubrication of natural joints and artificial joints. The first of these presents the various theories of natural joint lubrication including microelastohydrodynamic lubrication, biphasic models, and boundary lubrication. The second section lists the various existing constructs of total hip replacement and their relative performance. This last chapter surveys 60 references in all.

Compared to the first edition, the second edition contains more than 70 new pictorial representations of recent research results. I trust that the reader will find these additions worthwhile.

Preface to the First Edition

Fluid film bearings are machine elements which should be studied within the broader context of tribology, "the science and technology of interactive surfaces in relative motion and of the practices related thereto."* The three subfields of tribology – friction, lubrication, and wear – are strongly interrelated. Fluid film bearings provide but one aspect of lubrication. If a bearing is not well designed, or is operated under other than the design conditions, other modes of lubrication, such as boundary lubrication, might result, and frictional hearting and wear would also have to be considered.

Chapter 1 defines fluid film bearings within the context of the general field of tribology, and is intended as an introduction; numerous references are included, however, should a more detailed background be required. Chapters 2, 3, and 4 outline classical lubrication theory, which is based on isothermal, laminar operation between rigid bearing surfaces. These chapters can be used for an advanced undergraduate or first-year graduate course. They should, however, be augmented with selections from Chapter 8, to introduce the students to the all-important rolling bearings, and from Chapter 9, to make the student realize that no bearing operation is truly isothermal. Otherwise, the book will be useful to the industrial practitioner and the researcher alike. Sections in small print may be omitted on first reading – they are intended for further amplification of topics. In writing this book, my intent was to put essential information into a rational framework for easier understanding. So the objective was to teach, rather than to compile all available information into a handbook. I have also included thought-provoking topics; for example, lubrication with emulsions, the treatment of which has not yet reached maturity. I expect significant advances in this area as it impacts on the environment.

The various chapters were read by Dr. M. L. Adams, Case Western Reserve University; Dr. M. Fillon, University of Poitiers, France; Dr. S. Jahanmir, National Institute for Standards and Technology; Dr. F. E. Kennedy, Dartmouth College; Mr. O. Pinkus, Sigma Inc.; Dr. K. R. Rajagopal, Texas A & M University; Dr. A. J. Szeri, University of California at Berkeley; and Dr. J. A. Tichy, Rensselaer Polytechnic Institute. However, in spite of the considerable assistance I received from various colleagues, any mistakes are mine alone.

The typing was expertly done by my daughter Maria Szeri-Leon and son-in-law Jorge Leon. I am grateful to them for their diligence and perseverance; not even their wedding interrupted the smooth flow of the project. I would also like to thank Ms. Florence Padgett, Editor at Cambridge University Press, for suggesting the project and for having confidence in me. My thanks are also due to Ms. Ellen Tirpak, Senior Project Manager at TechBooks, for providing expert editing of the manuscript.

*British Lubrication Engineering Working Group, 1966.