

HYDRAULIC FAILURE ANALYSIS

**Fluids, Components,
and System Effects**

**George E. Totten
David K. Wills
Dierk G. Feldmann**

EDITORS



STP 1339

STP 1339

Hydraulic Failure Analysis: Fluids, Components, and System Effects

George E. Totten, David K. Wills, and Dierk G. Feldmann, editors

ASTM Stock Number: STP1339



ASTM
PO Box C700
100 Barr Harbor Drive
West Conshohocken, PA, 19428-2959

Printed in the U. S. A.

ISBN: 0-8031-2883-5

ISSN:

Library of Congress Cataloging-in-Publication Data

Hydraulic failure analysis : fluids, components, and system effects / George E. Totten, David K. Wills, and Dierk G. Feldmann, editors.

p. cm. — (STP ; 1339)

“ASTM Stock Number : STP1339.”

Includes bibliographical references and index.

ISBN 0-8031-2883-5

1. Oil hydraulic machinery. 2. System failures (Engineering) I. Totten, George E. II. Wills, David K., 1945- III. Feldmann, Dierk G., 1940- IV. ASTM special technical publication 1339.

TJ843 .H912 2001

621.2'0424—dc21

2001022197

Copyright © 2001 AMERICAN SOCIETY FOR TESTING AND MATERIALS, West Conshohocken, PA. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

Photocopy Rights

Authorization to photocopy items for internal, personal, or education classroom use, or the internal, personal, or educational classroom use of specific clients, is granted by the American Society for Testing and Materials (ASTM) provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923; Tel: 978-750-8400; online: <http://www.copyright.com/>.

Peer Review Policy

Each paper published in this volume was evaluated by two peer interviewers and the editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were prepared “camera-ready” as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. In keeping with longstanding publication practices, ASTM maintains the anonymity of the peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Foreword

This publication, *Hydraulic Failure Analysis: Fluids, Components, and System Effects*, contains papers presented at the symposium of the same name held in Reno, Nevada, on 5–6 December 1999. The symposium was sponsored by Committee D-2 on Petroleum Products and Lubricants. The symposium co-chairmen were George E. Totten, Union Carbide Corporation, David K. Wills, Sauer-Danfoss, and Dierk G. Feldmann, Technical University Hamburg-Harburg.

Contents

Overview	ix
SESSION I: THEORY, MECHANISM, AND SIMULATION	
Tribological Design: A Real World Approach—K. C. LUDEMA	3
Mechanisms of Abrasive Wear in Lubricated Contacts—J. A. WILLIAMS AND A. M. HYNICICA	13
Tribology of Hydraulic Systems: Hydrodynamic Effects of Surface Roughness— K. TØNDER	31
Lubrication Characteristics on Sliding Surfaces in a Piston Pump and Motor During Running-In Tests—K. TANAKA, K. KYOGOKU, AND T. NAKAHARA	41
Elastic-Plastic Finite Element Stress Analysis of Two-Dimensional Rolling Contact— Y. JIANG, J. CHANG, AND B. XU	59
Development of a New Application-Related Test Procedure for Mechanical Testing of Hydraulic Fluids—D. G. FELDMANN AND M. KESSLER	75
Modeling Abrasive Wear of Homogeneous and Heterogeneous Materials—K. ELALEM, D. Y. LI, M. J. ANDERSON, AND S. CHIOVELLI	90
Hydraulic Gear Pump Failure Analysis and Tribology Simulation—L. D. WEDEVEN AND R. BOURDOULOUS	105
Corrosive Wear in Hydraulic Systems: An Overview—H. LIANG AND G. E. TOTTEN	119
SESSION II: FAILURE ANALYSIS - PART 1	
Root Cause Analysis to Identify Hydraulic Failure Modes—J. REICHEL AND M. WAHL	137
Failure Analysis of the Hydraulic Drive System in a Storm Surge Barrier—M. FLUKS	150
Analysis of Failure Modes of a Military Hydraulic Fluid: MIL-H-46170— R. B. MOWERY AND E. M. PURDY	167

SESSION III-A: FAILURE ANALYSIS - PART II

Wear Particle Analysis—J. POLEY	179
Problems and Possibilities with Bottle Sampling for Assessment of Particle Concentration—G. C. SVEDBERG AND K. SUNDVALL	190
Wear and Wear Debris in a Changing World—B. J. ROYLANCE	200
Advanced Strategies for the Monitoring and Control of Water Contamination in Oil Hydraulic Fluids—D. D. TROYER	214
Advancements in Fluid Analysis Technologies and Strategies for Hydraulic System Condition-Based Maintenance—J. C. FITCH	225
Hydraulic Pump Contaminant Wear—R. K. TESSMANN AND I. T. HONG	248
Piston Pump Failures in Various Type Hydraulic Fluids—S. OHKAWA, A. KONISHI, H. HATANO, AND D. VOSS	263
Fundamental Hydraulic Wear Processes—H. LIANG, K. MIZUNO, G. E. TOTTEN, R. J. BISHOP, JR., AND S. LEMBERGER	278
Analysis of Common Failure Modes of Axial Piston Pumps—C. G. FEY, G. E. TOTTEN, AND Y. H. SUN	299
Effect of Pump Inlet Conditions on Hydraulic Pump Cavitation: A Review—R. J. BISHOP, JR. AND G. E. TOTTEN	318
The Influence of Surface Topography and Environment on the Fatigue Life of a Hydraulic Motor—W. SCOTT	333
TRIZ-Based Root Cause Failure Analysis for Hydraulic Systems—D. L. MANN AND E. J. HUGHES	340

SESSION IV-A: MATERIALS

The Surface Behavior of Metallic Materials During the Incubation Period of Cavitation Erosion—A. YABUKI, K. NOISHIKI, K. KOMORI, AND M. MATSUMURA	357
Failure Mechanism of a Hydraulic Log Piston and Slipper Assembly—J. T. SIKES	370
Development of Pseudoelastic TiNi Tribo Materials—D. Y. LI	382
Research of Suitable Material Pairs for Applications Operating with High Water-Based Fluids—R. OBEREM AND H. MURRENHOF	402
Ceramic Parts for Hydrostatic Pumps and Motors—D. G. FELDMANN	417

PVD-Coatings-Applications in Fluid Power Technology—D. VAN BEBBER AND H. MURRENHOF	427
Improving Tribological Performance of Mechanical Components by Laser Surface Texturing—I. ETISON, G. HALPERIN, AND G. RYK	441
SESSION III-B: COMPONENTS—SEALS, VALVES, AND ROLLING ELEMENT BEARINGS	
An Investigation of Fundamental Blistering Phenomena in Rotary Lip Sealing— F. SCHULZ, V. M. WOLLESEN, AND M. VÖTTER	451
Influence of Lubrication on Wear and Friction on O-Rings in Contact with Yellow Metal—M. VÖTTER AND O. SCHULTZ	462
Hydraulic Valve Problems Caused by Oil Oxidation Products—A. SASAKI	474
Rust Inhibitor Contamination-Related Problems in Military Aircraft Hydraulic Systems—S. K. SHARMA, C. E. SYNDER, JR., L. J. GSCHWENDER, J. C. LIANG, AND B. F. SCHREIBER	489
Extending Rolling Element Bearing Life in Hydraulic Systems with Water-Based Fluids-The Grease Lubrication Option—G. W. POLL	500
SESSION IV-B: FLUIDS	
The Importance of Shear Stability in Multigraded Hydraulic Fluids— C. W. HYNDMAN, B. G. KINKER, AND D. G. PLACEK	523
Corrosive Wear Behavior of 304 Stainless Steel and its Variation with Alloyed Oxygen-Active Element Yttrium—T. ZHANG AND D. Y. LI	535
A Study of the Mechanism for Beneficial Effects of Yttrium Additive in Lubricant on Corrosive Wear and Friction of Metals—R. LIU AND D. Y. LI	549
The Effect of Oil Type on Wear in Fluid Power Components—T. KOIVULA, R. KARJALAINEN, E. ELLMAN, AND M. VILENIUS	563
Recent Experiences with Ester Based Fluids in Qualification Tests—D. G. FELDMANN AND M. KESSLER	575

Overview

Problems in hydraulic systems associated with hydraulic fluids have been an important area of investigation for many years. Of equal importance is the mutually dependent interaction of hydraulic fluids with component design, component metallurgy, and the design of the hydraulic system itself. Investigation related to these important areas include the following:

- The effect of fluid chemistry on component failure as the result of oxidation, wear debris, viscosity loss, generation of corrosion by-products, and yellow metal wear.
- Metallurgy of the material, including material pair effects and physical properties.
- The effect of surface finish.
- Modeling wear mechanisms as a function of material pair contact loading, speed, and other factors.
- Dynamic versus static wear.
- Wear mechanisms including rolling contact fatigue, cavitation, lubrication failure, abrasive wear, and others, in addition to combinations of these mechanisms.
- Methods of failure analysis focusing on strategies to identify root causes of failure.
- Hydraulic component design and metallurgy of bearings, gears, slippers, and end-plates.

Since there are relatively few, if any, books published that provide a comprehensive overview of these issues, an International Symposium on Hydraulic Failure Analysis, Fluids, Components and System Effects was held in Reno, Nevada on December 5–6, 1999. The objective of this conference was to address these issues and to provide an insight into new technologies that are being developed to address hydraulic wear and failure problems.

The first paper in the first section of this book: Theory, Mechanism, and Simulation provides a thorough overview of the importance of tribological design. Many hydraulic wear and failure problems could be eliminated if appropriate design principles were employed. The remaining papers in this section, taken together, provide the reader with a thorough overview of fundamental principles involved in hydraulic lubrication and wear and set the stage for the wide range of topics discussed in the remainder of the book.

The second section of the book, Failure Analysis, provides a wide range of discussion on numerous topics related to hydraulic failure analysis. These include: methodologies for root cause analysis to identify hydraulic wear, importance and different applications of wear particle analysis to identify the sources of hydraulic component failure, and a failure catalog of hydraulic pump and rolling element bearing wear provided by the examples given in the papers comprising this section.

The third section of this book, **Materials**, provides an overview of significant research underway to identify superior materials for hydraulic pump and component design. The areas of research include: effect of material selection on cavitation erosion, surface engineering to improve material properties, and surface texturing.

Hydraulic wear and failure is not limited to hydraulic pumps and motors. The fourth section, **Components—Seals, Valves and Rolling Element Bearings**, addresses the effects of various wear, selected failure mechanisms of hydraulic seals, and yellow metal wear.

The last section of the book is **Fluids**. The papers provided in this section discuss the effects of fluid shear stability, additives, and bio-oils on hydraulic pump wear.

The information provided in this book make it an excellent resource for the hydraulic design engineer and maintenance engineer to properly design, maintain, and troubleshoot a hydraulic system. Additionally, the tests and recommendations made by the speakers at this conference will be carefully analyzed within the ASTM D.02N subcommittee to determine their applicability for the development of new ASTM standards and guides.

George E. Totten

Union Carbide Corporation
Tarrytown, NY, USA
Symposium Co-Chairman and Editor

David K. Wills

Sauer-Danfoss
Ames, IA, USA
Symposium Co-Chairman and Editor

Dierk G. Feldmann

Technical University of Hamburg-Harburg
Hamburg, Germany
Symposium Co-Chairman and Editor

ISBN 0-8031-2883-5

Hydraulic Failure Analysis: Fluids, Components, and System Effects. George E. Totten, David K. Wills, and Dierk G. Feldmann, editors. ASTM Stock Number: STP1339. This publication, Hydraulic Failure Analysis: Fluids, Components, and System Effects, contains papers presented at the symposium of the same name held in Reno, Nevada, on 5-6 December 1999. The symposium was sponsored by Committee D-2 on Petroleum Products and Lubricants. The symposium co-chairmen were George E. Totten, Union Carbide Corporation, David K. Wills, Sauer-Danfoss, and Dierk G. Feldmann, Technical University Hamburg-Harburg. Hydraulic Failure Analysis: Fluids, Components, and System Effects. STP 1339. The third section of this book, Materials, provides an overview of significant research underway to identify superior materials for hydraulic pump and component design. The areas of research include: effect of material selection on cavitation erosion, surface engineering to improve material properties, and surface texturing. Hydraulic wear and failure is not limited to hydraulic pumps and motors. The fourth section, Components--Seals, Valves and Rolling Element Bearings, addresses the effects of various wear, select Request PDF | On Jan 1, 2001, H. Liang and others published Hydraulic failure analysis: Fluids, components, and system effects | Find, read and cite all the research you need on ResearchGate. The main reason for the loss of efficiency and performance of hydraulic systems is the erosion of system components due to the detrimental effect of abrasive wear, cavitation, corrosion and silt [1][2][3][4][5]. Superhydrophobic coatings are designed for use as a passive method of protecting materials and are expected to become a.