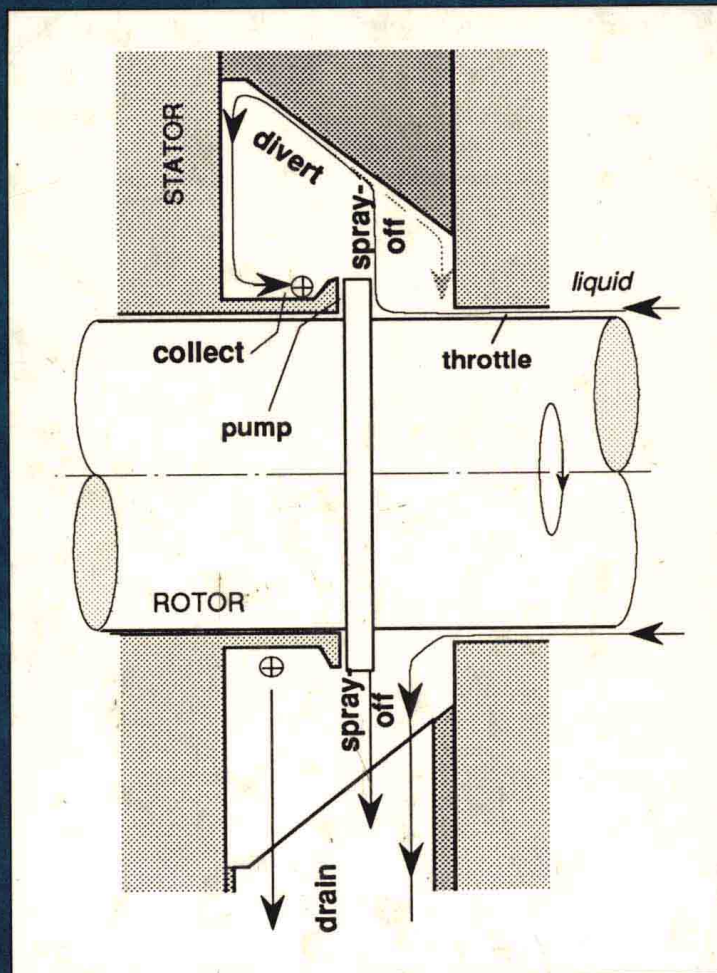


Dr. B. S. Nau
editor

Fluid Sealing



bH Group

ISBN 0-7923-1669-X

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Front cover diagram courtesy of E. Fritz *et al.*, University of Stuttgart, Germany.

All Rights Reserved

© 1992 Kluwer Academic Publishers

No part of the material protected by this copyright notice may be reproduced or
utilized in any form or by any means, electronic or mechanical,
including photocopying, recording or by any information storage and
retrieval system, without written permission from the copyright owner.

Printed by Information Press Ltd., Oxford, England

FLUID SEALING

FLUID MECHANICS AND ITS APPLICATIONS

Volume 8

Series Editor: R. MOREAU

MADYLAM

Ecole Nationale Supérieure d'Hydraulique de Grenoble

Boîte Postale 95

38402 Saint Martin d'Hères Cedex, France

Aims and Scope of the Series

The purpose of this series is to focus on subjects in which fluid mechanics plays a fundamental role.

As well as the more traditional applications of aeronautics, hydraulics, heat and mass transfer etc., books will be published dealing with topics which are currently in a state of rapid development, such as turbulence, suspensions and multiphase fluids, super and hypersonic flows and numerical modelling techniques.

It is a widely held view that it is the interdisciplinary subjects that will receive intense scientific attention, bringing them to the forefront of advancement. Fluids have the ability to transport matter as well as to transmit force, therefore fluid mechanics is a subject that is particularly open to cross fertilisation with other sciences and disciplines of engineering. The subject of fluid mechanics will be highly relevant in domains such as chemical, metallurgical, biological and ecological engineering. This series is particularly open to such new multidisciplinary domains.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of a field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

For a list of related mechanics titles, see final pages.

ACKNOWLEDGEMENTS

The valuable assistance of the Technical Advisory Committee and panel of referees is gratefully acknowledged.

TECHNICAL ADVISORY COMMITTEE

| | |
|----------------------------|--|
| Mr B D Halligan (Chairman) | James Walker & Co Limited |
| Mr P Dolan | BP Engineering |
| Mr M S Dosanjh | British Gas plc |
| Mr T G Doust | John Crane International |
| Mr B Dühring | WS Shamban Europa A/S |
| Mr A Gabelli | SKF Engineering and Research Centre BV |
| Mr C Gee | Gee Graphite Limited |
| Mr H F Ibbott | Esso Engineering (Europe) Ltd |
| Dr B S Nau | BHR Group Limited |
| Dr N A Peppiatt | Hallite Seals International Ltd |
| Mr J Plumridge | EG & G Sealol |
| Prof M T Thew | University of Southampton |
| Mr N Wallace | Flexibox Limited |

CORRESPONDING MEMBERS

| | |
|-------------------|--------------------------------------|
| Prof A Bazergui | Ecole Polytechnique Montreal, Canada |
| Mr D Buchdahl | EDF, France |
| Prof Y Gu | University of Petroleum, China |
| Dr F Hirano | Kyushu University, Japan |
| Dr D E Johnston | Carl Freudenberg, Germany |
| Mr C X Latty | Latty International, France |
| Dr A O Lebeck | Mechanical Seal Technology Inc, USA |
| Dr R Metcalfe | Atomic Energy of Canada Ltd, Canada |
| Prof H K Müller | Universität Stuttgart, Germany |
| Mr R Münnich | Martin Merkel GmbH & Co KG, Germany |
| M G Pierron | PMB & Associés, France |
| Mr T Pugh | Conoco Inc, USA |
| Prof R F Salant | Georgia Institute of Technology, USA |
| Mr H J Tückmantel | Kempchen & Co GmbH, Germany |

FOREWORD

With this 13th in the series of International Conferences on Fluid Sealing these meetings move into their third decade. To be precise it is now thirty-one years since BHRA, as it then was, convened, with no little trepidation, the first of these Conferences in Ashford, England. The massive set of proceedings now occupies a considerable length of shelf in my bookcase and represents a tremendous technological resource - over 400 separate papers. It is interesting that I seem to refer most often to the earlier volumes, probably most of all to the very first. Perhaps this is because this volume marks the beginning of "historic times", AD 0, for fluid sealing technology. There were of course important publications in this field even before 1961. A notable example is the seminal work of my predecessor at BHRA, Dr D.F.Denny, whose researches on reciprocating fluid power seals, "The sealing mechanism of flexible packings", was published in 1947 by a long since defunct government department, the Ministry of Supply. Another notable source is the Proceedings of the Institution of Mechanical Engineers' 1957 Conference on Lubrication and Wear. However, there is more to fluid sealing technology than just tribology, as we must now call lubrication and wear, interest in static seals has really come to the fore in recent years - witness the large batch of papers dealing with this subject in the present Conference. Much of our developing understanding of this branch of fluid sealing technology, a trivial design problem to the uninitiated, has largely resulted from the results of research carried out on a co-operative basis by users, suppliers and research organisations in groups variously centered in North America, continental Europe and the UK. Such collaborative projects are a cost effective way of advancing technology, sharing the cost to achieve a desirable common goal. Here at BHR Group Ltd (formerly BHRA) the Fluid Sealing Technology Group has such collaborative activities in such diverse areas as mechanical seals, fluid power seals, elastomer seal life prediction and, not least, high-duty bolted joints. These grew out of partly government funded projects for UK Companies but have long since extended to encompass pan-European and global projects. This broad geographical scope is also reflected by the authorship of the papers printed in this volume, who come from very diverse regions of the world, but united by a common interest in fluid sealing technology and a common desire to play a part in making industry more efficient and the earth a better place to live.

Dr Bernard Nau, Cranfield, January 1992

**13th International Conference on
FLUID SEALING
Brugge, Belgium : 7-9 April 1992**

| | |
|---|-----|
| Foreword | xi |
| B Nau : BHR Group Ltd | |
| Abstract of Opening Address : Seals - Machine Elements of Increasing Importance | 1 |
| S Ioannides : SKF Engineering and Research Centre BV, Netherlands | |
| LIP SEALS | |
| Keynote Address : Understanding the Sealing Mechanism of the Radial Lip Seal for Rotating Shafts | 5 |
| L A Horve : C R Industries, USA | |
| Computation and Measurement of Sealing Contact Stress and its Role in Rotary Lip Seal Design | 21 |
| A Gabelli, F Ponson, G Poll : SKF Engineering & Research Centre BV, Netherlands | |
| On the Sealing Mechanism of Lip Seals Containing Microundulations | 41 |
| R F Salant : Georgia Institute of Technology, USA | |
| Dynamic Mapping of Radial Lip Seal Lubricant Films by Optical Resonance Techniques | 55 |
| G Poll, A Gabelli, P Binnington : SKF Engineering & Research Centre BV, Netherlands; J Qu : CR Industries, USA | |
| STATIC SEALS | |
| Duty Limits of Sheet Gaskets in Steam Joints. | 81 |
| B S Nau, M D Reddy : BHR Group Ltd, UK | |
| Fundamental Study of Static Sealing Characteristics of Solidified Oils at High Pressure | 109 |
| F Hirano : Kyushu University; N Ohno : Saga University, Japan | |
| Sealing of Large Size Vessels | 121 |
| M Lefrancois : Le Carbone-Lorraine, France | |
| Low Pressure System High Integrity Seal Concept - The Low Stress Spiral Wound Gasket | 133 |
| K P Allen, G Briggs : Flexitallic Ltd, UK | |
| Water and Steam Tightness Tests of Expanded Graphite Static Gaskets for Nuclear Power Plant Steam Generators | 141 |
| J C Vignaud, P Digat, H Nowak : EDF, France | |
| EDF Approach to the Design and Maintenance of Leaktight Bolted Assemblies | 157 |
| J Rizo : EDF/SEPTEN, France | |

| | |
|---|-----|
| Selco Seal - Applications and Test Results | 165 |
| J Paterson, M Lowry : Sealing Corporation, USA | |
| Development of Test Procedures for Fire Resistance Qualification of Gaskets | 193 |
| M Derenne, L Marchand, A Bazergui : École Polytechnique, Canada; J R Payne : JPAC Inc, USA | |
| Recent Developments in Elevated Temperature Gasket Evaluation | 209 |
| L Marchand, A Bazergui, M Derenne : École Polytechnique, Canada | |
| Testing of Gaskets in a Din Flange Before and After Storage at Elevated Temperature | 225 |
| A Hirschvogel : SIGRI GmbH, Germany | |
| Development of Test Facility to Characterize Static Seals at Temperature up to 800°C | 235 |
| Y Birembaut, T Ledauphin : CETIM; E Inghels, E Poulin : SEP, France | |
| Non Circular Pressure Vessel Flanges - New Design Methods | 247 |
| A E Blach : Concordia University, Canada | |
| MECHANICAL SEAL RESEARCH | |
| Experimental Analysis of the Optimum Lubrication Conditions for Mechanical Seals | 269 |
| B Tournerie, J Frene : Université de Poitiers; M Lepine : Jeumont Schneider Industrie, France | |
| Identification of Friction Modes and Analysis of Friction Characteristics of Mechanical Face Seals | 289 |
| Y Q Gu : University of Petroleum, China | |
| Cavitation - A little Noticed Factor in the Operation of Mechanical Seals | 301 |
| D Zeus : Feodor Burgmann Dichtungswerke GmbH & Co, Germany | |
| MECHANICAL SEAL APPLICATION AND PERFORMANCE | |
| Mechanical Seal Performance for Low Emissions of Volatile Organic Compounds | 313 |
| W E Key, G Wang, K Lavelle : BW/IP International Inc, USA | |
| Mechanical Seals for Abrasive and Clogging Medias | 333 |
| J Bratthäll : ITT Flygt, Sweden | |
| A Statistical Review of Mechanical Seal Failures in Process Plant Pumps | 347 |
| P A Conner, M T Thew : University of Southampton, UK | |
| Predicting and Ensuring the Performance of Hard Faced Seals | 369 |
| N M Wallace : Flexibox Ltd, UK | |
| Analysis, Design and Laboratory Testing of a High Pressure High Speed, Reduced Axial Length Gas Seal | 389 |
| J F Gardner, P Basu, R Mukami : E G & G Fluid Components Technology Group R&D, | |

MECHANICAL SEAL QUALIFICATION

- Mechanical Seal Review** 413
P J Dolan : BP Engineering, UK
- Mechanical Seals Qualification Procedure of the Main Pumps of Nuclear Power Plants in France** 429
D Buchdahl, R Martin, J-M Girault : EDF, France
- Performance Testing of Mechanical Seals** 441
R K Flitney, B S Nau : BHR Group Ltd, UK
- A Lubrication Number for Mechanical Seals** 467
D J Schipper : University of Twente; A J Hoevenaar : Delft University of Technology; B de Laat, S Bakx, J T Keijer : BW/IP International BV, Netherlands

MATERIALS AND THERMAL

- Study of Mechanism and Controlling Factors of Carbon Blister Generation on Mechanical Seals** 479
Z Uchibori, T Shimomura, H Hirabayashi : Eagle Industries Co Ltd, Japan
- Investigation on Surface Failure of Hard Materials for Mechanical Seals** 495
M Komiya, S Matsui, H Hirabayashi : Eagle Industries Co Ltd, Japan
- Thermal Cycling in Mechanical Seals - Causes, Prediction and Prevention** 507
A Parmar : John Crane International, UK
- A Study of the Mechanochemical Factors Degrading the Performance of Rubber Seals** 527
Y Kanzaki, H Nishina, S Nagasawa, Y Kawahara : NOK Corporation, Japan

PACKINGS

- A New Mechanical Packing Concept Brings Secure Stem Sealings with Rapid Response to Modulating Control Valves** 557
C X Latty : Latty International SA, France
- Sealing Performances of Gland Packings for Valves in Nuclear Plant** 567
K Hayashi, K Hirasata, T Nagatomo : Osaka Sangyo University, Japan
- Seal System Development for Large Centrifugal Pumps in Arduous Conditions** 581
D Buchdahl, D Kempf : EDF France; R Elliott : James Walker & Co Ltd, UK
- Theoretical Analyses and Experimental Studies of Reliability and Stability of the Gland Packing** 605
Y Q Gu, M Hao : University of Petroleum, China

FLUID POWER

- Compatibility of Elastomeric Seal Materials in Modern Hydraulic Pressure Fluids 627
J G Peschk : Carl Freudenberg, Germany
- Contact Hydraulics in the Sealing Footprint - Effects on Deformation, Leakage and Friction of Soft Seals 655
R Metcalfe, S B Baset, S Kuran : AECL Research, Canada
- Finite Element Redesign of Reciprocating "PTFE" Rod Seals 671
P Botto, E Dragoni, A Strozzi : Universita' degli Studi di Bologna, Italy
- PTFE-Shaft Seal for Higher Pressures 685
H K Müller, P Wäsche : Universität Stuttgart, Germany

VALVE EMISSIONS AND CLEARANCE SEALS

- Emission Control in Control Valves & Related Equipment 695
K R Thondukolam : E I Dupont de Nemours Company, USA
- Liquid Collecting Labyrinth Seals for Machine Tool Spindles 703
E Fritz, W Haas, H K Müller : Universität Stuttgart, Germany
- The Design and Development of a Novel Low Cost Elastomeric Mechanical Seal 711
C J Fone, J Gilbert : John Crane International, UK

SEALS - MACHINE ELEMENTS OF INCREASING IMPORTANCE

PROFESSOR E. IOANNIDES
SKF Engineering & Research Centre B.V.
Imperial College of Science, Medicine & Technology

ABSTRACT

With the advent of the Industrial Revolution, moving machinery, containment of pressure, separation of fluids and many other conditions which require what we collectively call sealing, arose. Seals that were used in those days are the forefathers of the many types of modern seals that comprise one of the most frequently used machine elements.

The evolution of seals and their development in the future reflects the technology of the day and consequently the needs of society. Societies are undergoing rapid changes. The population growth is coupled to the high growth of information and communication systems, leading to an explosion of knowledge. The consequence of this is the speeding up of the rate of technological breakthroughs but also more sophisticated and demanding customers and end users.

When the above is coupled to the intense competition in today's markets, it follows that products (and, by implication, their components such as seals) are required to have higher reliability in order that they fulfil the "trouble-free operation" demands of the end user. At the same time, because of the strong competition, there is an increasing demand for "downsizing", that is, scaling down of machinery or increasing the power throughput for the same size. These two requirements of reliability and downsizing apply to seals as components but also provide a clue to the increasing use of seals as a protective element to obtain the best performance out of machinery. A notable example is the sealing of rolling element bearings where the exclusion of particulate contamination

can increase the life of the bearing by two orders of magnitude. In recent years there has been a strong increase in the demand for sealed-for-life bearings and some 70% of the smaller size deep groove ball bearings are produced in this manner. Moreover, the protection of our fragile environment is today of global concern. In many cases it is therefore necessary to provide the reverse protection, that is, protect the environment from fluids used in machinery and various installations. This is another reason for increasing demands for effective sealing.

Finally, the market competition requires faster product development. This in turn calls for effective research activities. This is particularly true for seals as in many cases even the *basic tribological mechanisms that govern the performance of seals* are not well understood. It is therefore important to continue exchanging valuable information on the results of research in conferences like the present one, and to maintain the progress in a difficult but promising field.

LIP SEALS

UNDERSTANDING THE SEALING MECHANISM OF THE RADIAL LIP SEAL FOR ROTATING SHAFTS

DR. LESLIE A. HORVE

INTRODUCTION

The elastomeric radial lip seal has been used throughout industry for many years to retain lubricants and exclude contaminants in rotating shaft applications. (Figure 1)

The sealing concept appears to be simple. The flexing of the elastomeric lip and the spring as they are installed over the shaft generates a force between the lip and the shaft that acts as a dam to keep fluid in and contaminants out of the sump. In actual practice, the sealing mechanism is not understood even though elastomeric lip seals have been used since the 1940's. This lack of understanding leads to trial and error in seal design, material compounding, and processing. The net result can be seals that leak instantly for no apparent reason. A different seal design and material may have sporadic performance with early leakers combined with long-lived seals. Trial and error can also result in a seal design and material that will function smoothly until the ultimate wear out mode is reached when the material loses its flexibility and can no longer follow the dynamics of the shaft. Garter springs are often used to add additional force which compensates for the load and flexibility loss that occurs when rubber materials are exposed to hot oil for extended periods of time. The many variables of lip design, material compounding, manufacturing processes and application conditions combine to make a complete understanding of the sealing mechanism a difficult task. Fortunately, many researchers have been studying the phenomena since the mid 1950's and progress has been accelerating recently.

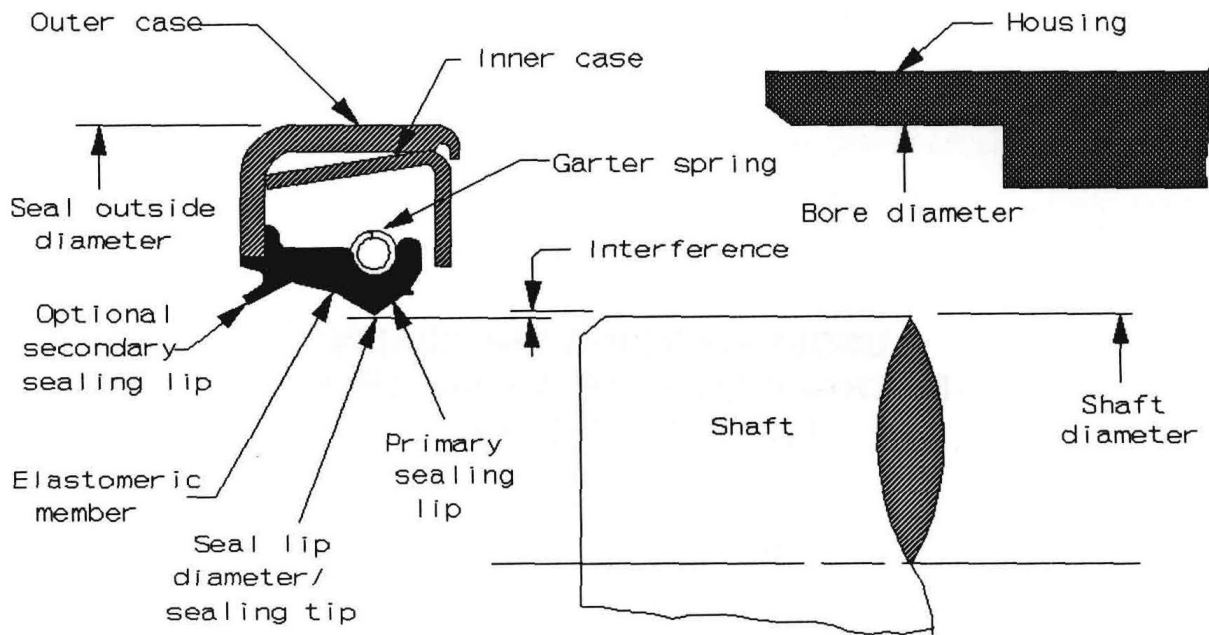


Figure 1. Typical Radial Lip Seal

COMPLEXITIES OF DEFINING THE SEALING MECHANISM

The sealing mechanism is that process that allows a lubricating film to exist between the seal lip and the rotating shaft without allowing leakage. This process is not completely understood even though researchers have been studying the problem for over 35 years. It is a fascinating research subject because many disciplines of engineering and science must be considered and there are many variables that may affect the sealing mechanism.

The field of mechanics is used to model the seal lip and predict the beam and stretch forces generated when the seal lip is placed on the shaft. Fluid dynamics is required to predict the flow of lubricant near and under the seal lip as the shaft rotates. Elastohydrodynamic theories must be employed to explain the formation and character of the thin lubricating film that exists between the shaft and the seal lip. The properties of the elastomer used to form the seal lip must be measured and studied to explain how the lip follows the dynamics of the eccentric, vibrating and rotating shaft. Both seal macrogeometry and the microgeometry found in the shaft and seal lip wear tracks must be considered when defining the sealing mechanism. The seal lip and shaft wear mechanism must also be studied. All of these complex phenomena must be considered and interfaced when formulating a model to understand the sealing mechanism.

COLLECTING CLUES

Many researchers have studied the radial lip seal and formulated theories to explain the sealing mechanism. Not all of these researchers have agreed because the problem is so complex and dynamic measurements to verify theories are difficult to make in the minute area between the seal lip and the shaft. There are observations and clues from the literature and experience that will simplify the problem and help focus research.

MACROSCOPIC EFFECTS AND OBSERVATIONS

- (a) Properly functioning seals will transfer or pump oil from the airside into the sump even if there is no oil in the sump [13].
- (b) Changes in seal lip length, seal lip thickness and lip to shaft interference do not significantly affect the sealing mechanism.
- (c) The oil side angle must be larger than the air side angle. Reversing these angles or installing the seal backwards causes the seal to leak profusely [1], [2]. (Figure 2)

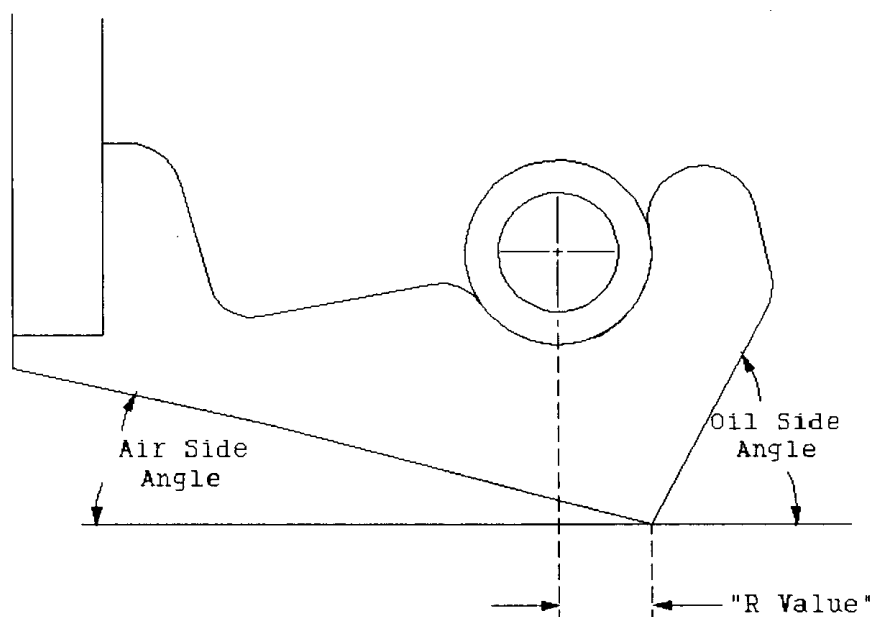


Figure 2. Seal macrogeometry affects the sealing mechanism