

Dissertation

Oil Condition Monitoring Using
Physical Chemosensors

ausgeführt zum Zwecke der Erlangung des
akademischen Grades eines Doktors
der technischen Wissenschaften von

Jochen Kuntner

eingereicht an der Technischen Universität Wien
Fakultät für Elektrotechnik und Informationstechnik

2007

The research presented in this thesis was carried out at the Industrial Sensor Systems group of the Institute of Sensor and Actuator Systems, Vienna University of Technology, Austria.

Erstbegutachter: Univ. Prof. Dr. Bernhard Jakoby
Johannes Kepler University Linz, Austria

Zweitbegutachter: Univ. Prof. Dr. Peter Hauptmann
Otto-von-Guericke-University Magdeburg, Germany

Schriftenreihe des Instituts für Sensor- und Aktuatorssysteme
Technische Universität Wien

Jochen Kuntner

**Oil Condition Monitoring Using
Physical Chemosensors**

Shaker Verlag
Aachen 2008

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Wien, TU, Diss., 2008

Copyright Shaker Verlag 2008

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 permission of the publishers.

Printed in Germany.

ISBN 978-3-8322-6955-5

ISSN 1866-1181

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

Internet: www.shaker.de • e-mail: info@shaker.de

Contents

Nomenclature.....	ix
List of Abbreviations.....	ix
List of Constants.....	x
List of Variables.....	x
Introduction.....	1
1.1 Online Oil Condition Monitoring	2
1.2 The Concept of Physical Chemosensors	2
1.3 Objective of the Thesis	6
Bibliography.....	7
Thermal Conductivity and Diffusivity Sensor	9
2.1 Heat Transfer Mechanisms	9
2.1.1. Heat Conduction	10
2.1.2. Heat Convection.....	14
2.1.3. Thermal Radiation.....	21
2.1.4. Heat Transfer in Liquids	23
2.2 Thermal Conductivity Sensors: A Review.....	25
2.2.1. Guarded Hot-Plate Method	27
2.2.2. Transient Hot-Wire Method.....	28
2.2.3. The 3 ω -Method.....	31
2.3 Hot-film Sensor.....	36
2.3.1. Sensor Design	36
2.3.2. Fabrication	38
2.3.3. Measuring Principle	39
2.3.4. Sensor Model	40
2.3.5. Measurement Setup.....	42
2.3.6. Experimental Results	44
2.4 Membrane-based Micromachined Sensor.....	49
2.4.1. Sensor Design	49
2.4.2. Fabrication	52
2.4.3. Measuring Technique Using Pulse-Based Excitation	53

2.4.3.1. Sensor Model.....	53
2.4.3.2. Measurement Setup	55
2.4.3.3. Experimental Results.....	57
2.4.4. Measuring Technique Using Sinusoidal Excitation	60
2.4.4.1. Sensor Model.....	61
2.4.4.2. Measurement Setup	64
2.4.4.3. Experimental Results.....	67
2.4.4.4. Numerical Study on the Membrane Influence.....	69
2.5 Bridge-based Micromachined Sensor	73
2.5.1. Sensor Design	73
2.5.2. Fabrication	78
2.5.3. Measurement Setup.....	79
2.5.4. Experimental Results	80
2.6 Determination of Thermal Thin-Film Properties	83
2.6.1. Sensor Design	83
2.6.2. Fabrication	86
2.6.3. Sensor Model	87
2.6.4. Measurement Setup.....	88
2.6.5. Experimental Results	89
2.7 Online TCR Determination of Thermistors	90
2.7.1. Sensor Design	91
2.7.2. Measurement Setup.....	91
2.7.3. Fabrication	91
2.7.4. Experimental Results	91
2.8 Conclusions and Outlook.....	94
Bibliography.....	95
Microacoustic Viscosity Sensor.....	101
3.1 Rheological Behavior of Fluids	101
3.2 Viscosity Measurement: A Review.....	106
3.2.1. Pressure Flow Viscometers	107
3.2.2. Drag Flow Viscometers	107
3.2.3. Microacoustic Viscosity Sensors	110
3.3 Microacoustic versus Classical Measurement	116
3.3.1. Microacoustic Sensing Mechanism.....	116
3.3.2. Measurement Setup.....	117
3.3.3. Experimental Results	119
3.4 Excitation of Spurious Compressional Waves	121
3.4.1. Mechanisms for Compressional Wave Excitation	122

3.4.2. Sensor Model	122
3.4.3. Experimental Results	123
3.5 Conclusions and Outlook.....	127
Bibliography.....	128
Summary	133
Zusammenfassung	137
Fabrication	141
Sensor Geometries	153
B.1 Dimensions of the Hot-film Sensor	153
B.2 Dimensions of the Membrane-based Sensor.....	154
B.3 Dimensions of the Bridge-based Sensor	156
B.4 Dimensions of the Cantilever-based Structures	157
B.5 Dimensions of the TCR Determination Sensor.....	160
List of Publications	163
Acknowledgements.....	165