Analysis Techniques for Racecar Data Acquisition

Other SAE books of interest:

Hands-On Race Car Engineer

By John H. Glimmerveen
(Product Code: R-323)

Kinetic Energy Recovery Systems for Racing Cars

Edited by Alberto Boretti
(Product Code: PT-159)

Engine Failure Analysis—Internal Combustion Engine Failures and Their Causes

By Stefan Zima and Ernst Greuter
(Product Code: R-320)

For more information or to order a book, contact SAE International at

400 Commonwealth Drive, Warrendale, PA 15096-0001, USA;
phone 877-606-7323 (U.S. and Canada only) or 724-776-4970
(outside U.S. and Canada); fax 724-776-0790;
email CustomerService@sae.org;
website <http://books.sae.org>.

Analysis Techniques for Racecar Data Acquisition, Second Edition

By Jörg Segers

Warrendale, Pennsylvania, USA

400 Commonwealth Drive
Warrendale, PA 15096-0001 USA

E-mail: CustomerService@sae.org
Phone: 877-606-7323 (inside USA and Canada)
724-776-4970 (outside USA)
Fax: 724-776-0790

Copyright © 2014 SAE International. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, distributed, or transmitted, in any form or by any means without the prior written permission of SAE International. For permission and licensing requests, contact SAE Permissions, 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA; email: copyright@sae.org; phone: 724-772-4028; fax: 724-772-9765.

ISBN 978-0-7680-6459-9
SAE Order Number R-408
DOI 10.4271/R-408

Segers, Jörg.
Analysis techniques for racecar data acquisition / by Jörg Segers. — Second Edition.

pages cm

Includes bibliographical references and index.

ISBN 978-0-7680-6459-9

1. Automobiles, Racing—Dynamics—Data processing. 2. Automobiles, Racing—Performance—Measurement. 3. Automobiles, Racing—Testing. I. Title.

TL243.S43 2014

629.28'2—dc23

2013037907

Information contained in this work has been obtained by SAE International from sources believed to be reliable. However, neither SAE International nor its authors guarantee the accuracy or completeness of any information published herein and neither SAE International nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that SAE International and its authors are supplying information, but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

To purchase bulk quantities, please contact:

SAE Customer Service
E-mail: CustomerService@sae.org
Phone: 877-606-7323 (*inside USA and Canada*)
724-776-4970 (*outside USA*)
Fax: 724-776-0790

Visit the SAE International Bookstore at

books.sae.org

Dedicated to Daan and Savitri

Contents

Preface to the Second Edition	xiii
Preface to the First Edition	xv
Acknowledgments	xvii
Chapter 1 Introduction	1
1.1 What Is This Book All About?	1
1.2 What Is Data Acquisition?	5
1.3 Hardware	11
1.4 Recent Hardware Trends	12
Chapter 2 Data Analysis Software Requirements	17
2.1 General Requirements for Data Acquisition Software	17
2.2 Different Ways of Displaying Data	18
2.3 Keeping Notes with Data Files	26
2.4 Mathematical Channels	28
2.5 Data Overlays	29
2.6 Filtering	30
2.7 Exporting Data to Other Software Packages	31
2.8 Getting Organized	32
Chapter 3 The Basics	39
3.1 Check the Car's Vital Signs	39
3.2 Lap Markers and Segment Times	45
3.3 Comparing Laps	48
3.4 Track Mapping	58
3.5 The Beginner's Data Logging Kit	62
3.6 A Possible Approach to the Testing of Sensor Readings	72
Chapter 4 Straight-Line Acceleration	77
4.1 Torque and Horsepower	77
4.2 Traction and Longitudinal Slip	83
4.3 TCS and Slip Ratios	88
4.4 Time versus Distance	92
4.5 The Importance of Corner Exiting Speed	93
4.6 Drag Racing Specifics	95

Chapter 5 Braking	101
5.1 Braking Quickness.....	101
5.2 Braking Effort.....	102
5.3 Braking Points	104
5.4 Lock-up.....	106
5.5 Brake Balance.....	107
5.6 Pedal Travel	114
5.7 ABS	114
5.8 Brake Temperature Measurement.....	116
Chapter 6 Gearing.....	123
6.1 Up-shifting	123
6.2 Down-shifting	131
6.3 The Gear Chart.....	133
6.4 Total Gear Ratio Channel.....	134
6.5 Determining Correct Gear Ratios	136
6.6 Determining in Which Gear to Take a Corner.....	136
Chapter 7 Cornering	139
7.1 The Cornering Sequence	139
7.2 The Traction Circle	142
7.3 Effects of Speed	148
7.4 Driver Activities That Indicate Vehicle Balance	152
7.5 The Understeer Angle.....	156
7.6 Vehicle Balance with a Yaw Rate Sensor	163
7.7 Front and Rear Lateral Acceleration.....	166
Chapter 8 Understanding Tire Performance	169
8.1 Estimating Grip Levels.....	169
8.2 Working with Tire Pressure Monitoring Systems.....	175
8.3 Working with Infrared Tire Temperature Sensors	180
8.4 Where Does Tire Temperature Come From?.....	182
8.5 Working Temperature Range of the Tires	184
8.6 Lateral Load Transfer and Tire Temperature.....	188
8.7 Tire Workload Distribution	193
8.8 Camber Evaluation with Tire Temperature Sensors.....	194
8.9 Tire Pressure Evaluation with Tire Temperature Sensors	196
Chapter 9 Quantifying Roll Stiffness Distribution.....	199
9.1 Measuring Suspension Roll Angle	199
9.2 The Roll Gradient	201

9.3	Using Roll Gradients as a Setup Tool	208
9.4	Front to Rear Roll Angle Ratio	212
9.5	Using the Roll Ratio as a Setup Tool	215
9.6	Suspension Troubleshooting	218
9.7	Pitch Gradient	219
Chapter 10 Wheel Loads and Weight Transfer		221
10.1	Lateral Weight Transfer	221
10.2	Longitudinal Weight Transfer	230
10.3	Banking and Grade Effects	231
10.4	Total Wheel Loads	234
10.5	Determining Wheel Loads with Modal Analysis	240
10.6	Measuring Wheel Loads with Suspension Load Cells	250
10.7	Tire Spring Rates	253
10.8	Chassis Torsion	255
Chapter 11 Shock Absorbers		257
11.1	Shock Absorber Velocity Analysis	257
11.2	Determining in Which Range to Tune the Shock Absorbers	260
11.3	Shock Speed Ranges	265
11.4	The Shock Speed Histogram	266
11.5	The Shock Speed Box Plot	279
11.6	Shock Speed Run Charts	282
Chapter 12 Suspension Analysis in the Frequency Domain . . .		287
12.1	Introducing Frequency Analysis	287
12.2	Frequency Analysis versus Time-Space Analysis	292
12.3	Theoretical Analysis	295
12.4	Suspension Optimization Using Frequency Analysis	303
12.5	Modal Analysis	304
12.6	Modal Frequency Issues	309
12.7	Nonlinear Considerations	315
12.8	Frequency Analysis from Sensor Data	316
Chapter 13 Aerodynamics		321
13.1	Aerodynamic Measurements	321
13.2	Air Density	323
13.3	Dynamic Pressure	326
13.4	Ride Height Measurement	328
13.5	Estimating Drag and Downforce from Logged Data	331
13.6	The Coast-down Test	334

13.7	The Constant Velocity Test	339
13.8	A Worked out Example of a Straight-Line Test.	343
13.9	Airbox Efficiency	350
Chapter 14 Analyzing the Driver		353
14.1	Improving Driver Performance.	353
14.2	Driving Style Evaluation	356
14.3	Throttle Application	357
14.4	Braking	368
14.5	Shifting Gears.	380
14.6	Steering	380
14.7	The Driving Line	383
14.8	Driver Consistency over Multiple Laps.	394
Chapter 15 Simulation Tools		395
15.1	Introduction	395
15.2	Suspension Kinematics Simulation.	397
15.3	Lap Time Simulation.	400
15.4	A Worked out Example.	418
15.5	How to Integrate Lap Time Simulation in Daily Data Acquisition Tasks.	421
15.6	Putting the Driver in the Simulation	423
Chapter 16 Using the Data Acquisition System for Race Strategy		431
16.1	Fuel Consumption.	431
16.2	Lap Time Variation During a Race	437
Chapter 17 Data Analysis Using Metrics.		443
17.1	What Are Metrics?	443
17.2	Why Use Metrics?	444
17.3	How to Create Metrics	446
Chapter 18 Track Data		453
18.1	What Can Be Learned from the Data about the Racetrack?	453
18.2	Racetrack Metrics	455
18.3	Speed and Gear Histograms	456
18.4	The Friction Circle.	457
18.5	How Bumpy Is the Track Surface?	459

Chapter 19 Introduction to Measurement	461
19.1 Introduction	461
19.2 Analog-Digital Conversion: Accuracy Implications	462
19.3 Sensor Selection and Application	464
19.4 Measurement Uncertainty	467
19.5 Temperature Sensors	472
19.6 Pressure Sensors	478
19.7 Displacement Sensors	481
19.8 Acceleration Sensors	482
19.9 Speed Sensors	484
19.10 Strain Gages	485
19.11 Torque Sensors	487
19.12 The Pitot Tube	488
19.13 Oxygen Sensors	489
19.14 GPS	490
19.15 Laser Distance Sensors	492
19.16 Surface Acoustic Wave Technology	494
List of Symbols	495
English Letters	495
Greek Symbols	501
References	503
Bibliography	505
Index	507
About the Author	515

Preface to the Second Edition

When the first edition of this book was first published in 2008, my goal was to create a book presenting up-to-date techniques to analyze data collected from onboard data logging systems in race cars. Since the first edition, I have received a great deal of feedback from people all over the world indicating that I was successful in obtaining this goal. I am extremely happy that this book has been able to fill a void in this ever-developing area.

However, since 2008 my personal understanding of this subject has evolved. First of all, the technology has developed, making it possible to obtain more advanced and accurate data regarding the performance of race cars at less cost. There are a number of observations that have led me to write this second edition.

Some race series have actively restricted data logging to decrease the team's running budgets. In these cases, it is extremely important that a maximum of information be extracted and interpreted from the hardware that is at hand. Although I do not agree with the philosophy of limiting data acquisition by sporting regulations, it does level the field, as everybody will have access to the same information. This means that a team that uses the data more efficiently will have an edge over the competition.

The opposite is also true. The ever-decreasing cost of electronics makes advanced sensors and logging capabilities more accessible for everybody. With this comes the risk of information overload. There will be a point where a team will no longer be able to process all the available data. Therefore, techniques need to be provided that will help in drawing the right conclusions quickly from very large data sets.

I wanted to include newly gained knowledge since the first publication. Experience is a continuous process, and I felt that the time had come to upgrade the book. There were some items in the first edition that needed to be addressed, explained better, or with more examples. The book contains three new chapters. The first (chapter 8) covers the techniques that are available to analyze tire performance. The second (chapter 17) gives an introduction to metric-driven analysis, a technique that is used throughout the book. Finally, a chapter was added to explain what kind of information the data contains about the track being driven on (chapter 18).

Preface to the First Edition

A proven way for athletes to be successful in any sporting discipline is for them to record their performance, analyze what has happened, and draw conclusions from the factors that influence that performance. Marathon runners log their running speed and distance along with their heart rate to optimize their training schedules. Football players record their games on video to evaluate techniques, performance, and tactics. Chess players write down every move in a game to replay and analyze it afterward. They measure something, learn from it, and try to use it to their advantage the next time.

In motor racing, sophisticated recording devices are used in conjunction with numerous sensors to record what the car and its driver are doing. Engineers often are employed full-time to maintain the system, analyze the recorded data, and draw the correct conclusions from it.

Motor racing is known for high-end technology, and this technology changes every day. Ten years ago, race car data acquisition was somewhat limited to well-funded teams in high-profile championships. Nowadays, the cost of electronics has decreased dramatically. Powerful computers are available for very little expense. Data acquisition systems are now sold for the price of a single racing tire. This means data acquisition has become accessible to everyone.

Whatever the price of the data acquisition system, it is a waste of money if the recorded data is not interpreted correctly. This book contains enough information to prevent the investment in a data acquisition system from being a waste of money.

Whether measuring the performance of a Formula One race car or that of a road-legal street car on the local drag strip, the dynamics of the vehicles and their drivers remain the same. Identical analysis techniques apply. This book contains a collection of techniques for analyzing data recorded by any vehicle's data acquisition system. It details how to measure the performance of the vehicle and driver, what can be learned from it, and how this information can be used to your advantage the next time the vehicle hits the track.

Acknowledgments

When I began working in motor racing in 1998, I soon learned that this business is a team effort. The sum of the qualities of each member determines the team's success. Eight years later, when I wrote this book, I learned this also is a team effort, very similar to running a successful racing team. That is why I would like to begin by appropriately crediting "my" team.

First, I would like to thank everyone at SAE International for guiding this project in the right direction. Special thanks go out to Martha Swiss, intellectual property manager, Heather Slater, product developer, Terri Kelly, administrative assistant, and Terry Wilson for artwork.

A big contributor to this book was Josep Fontdecaba I. Buj, engineering director at Creuat S.L.; not only for writing chapter 12 but especially for the many discussions we had about suspension setup and data analysis. His input added immeasurable value to this book.

David Brown and Andrew Durant at Race Technology gave me detailed insight about GPS-based data acquisition techniques. I would like to thank them for providing me with the hardware that was used to create much of the data traces used throughout this book. Their company is proof that data acquisition can be affordable for all motor racing disciplines.

I am proud to have Cosworth Electronics support the creation of this book. The information and analysis files supplied by this company were invaluable. Thanks go out to Thomas Buckler, Robert Kirk and Michael de Cock.

The following people deserve credit for taking the time to evaluate the manuscript and for providing me with invaluable feedback: Peter Wright (consultant to the FIA), Dr. Wolfgang Ullrich (head of Audi Sport), John Glimmerveen (author of the book *Hands-on Racecar Engineer*), Doug and Bill Milliken (authors of the book *Racecar Vehicle Dynamics*), and William C. Mitchell (head of Mitchell Software).

This book addresses what I know about race car data acquisition, and what I know is influenced greatly by the people I had a chance to work with. Therefore, my great respect goes out to all the engineers, mechanics, and team owners that were there to teach me. I hope I can repay these debts when they read this book.

Every graph in this book was created by a race car driver. Many of these graphs resulted in successful track performance, pole positions, race victories, and championships. I thank all of these drivers for providing me with data to analyze.

Acknowledgments

Henrik Roos of the Simbin Development Team is the person that triggered my interest in technical writing. He gave me the idea to write a book on this little-documented subject in the first place.

Special thanks for this second edition go out to Pierre-Alain Aucouturier and Philippe Leuwers at Texys Sensors for their support and detailed supply of information on the latest sensor technologies. Also Giuseppe Callea of BHA I TECH srl. deserves special mention for his contribution in chapter 3 on the evaluation of sensor reading accuracies and the interesting discussions on simulation techniques.

I would like to thank Tony Gardner and David Tucker of iRacing.com for their help with the chapter on simulation. The first edition of this book proved quite popular in the online racing community. It surprised me to find out how close something—that is often wrongfully considered as a computer game—resembles real racing. I am sure that this interest group will find a lot of useful information in this book.

Jörg Segers