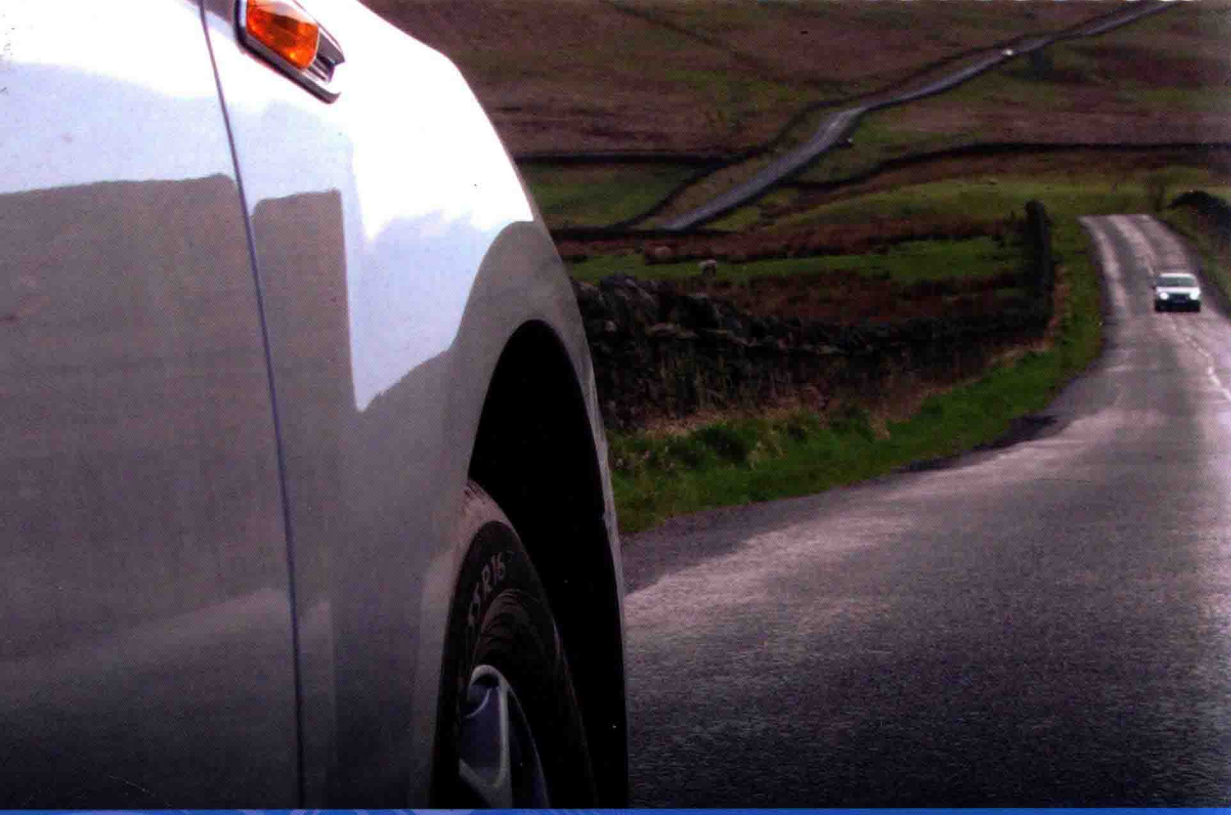

VEHICLE POWERTRAIN SYSTEMS

Behrooz Mashadi | David Crolla

WILEY

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Behrooz Mashadi
Iran University of Science and Technology

David Crolla
University of Sunderland, UK

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VEHICLE POWERTRAIN SYSTEMS

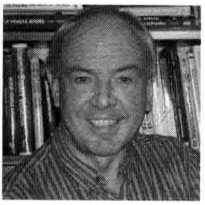
This book is dedicated to Professor David Crolla who passed away unexpectedly while the book was in production. David led an unusually full and productive life both in work and play, achieving great success and popularity. David was a leading researcher, an inspiring teacher, an excellent supervisor of research postgraduates and a friend to many. David's energy, enthusiasm and irrepressible humour made a lasting impression on me and everyone who knew him. He is sorely missed and his essential contribution to the publication of this book will always be remembered.

About the Authors

Behrooz Mashadi is an Associate Professor in the Department of Automotive Engineering, Iran University of Science and Technology (IUST), Tehran, Iran. He received his BSc and MSc in Mechanical Engineering from Isfahan University of Technology (IUT), Isfahan, Iran, and his PhD degree in Vehicle Dynamics Engineering from the University of Leeds, in 1996 under the supervision of Professor D. A. Crolla. He was then engaged in several R&D projects in the automotive engineering industry and joined the academic staff at IUST in 2002.

He has developed and taught a wide range of courses for undergraduate and postgraduate students in the field of Automotive Engineering. He served as Deputy for Education in the Department of Automotive Engineering and is currently Deputy of the Automotive Research Centre at IUST, which is the leading centre for automotive R&D in Iran.

His current research interests include vehicle powertrain systems, hybrid propulsion systems, vehicle dynamics, vehicle modelling, simulation and control. He has presented and published over 100 papers in journals and conferences. He also serves on the editorial board of several international journals.



David Crolla, FREng, was a Visiting Professor of Automotive Engineering at the Universities of Leeds, Sunderland and Cranfield. After graduating from Loughborough University, he first worked as a research engineer in off-road vehicle design, and then joined the University of Leeds (1979–2001) becoming head of the Mechanical Engineering Department. His research interests included vehicle dynamics, chassis control systems, powertrain systems, suspensions and terramechanics, and he had published and presented over 250 papers in journals and conferences.

His activities included research in low carbon vehicles, industrial short courses in vehicle dynamics and chassis control, and engineering consultancy, for example, the BLOODHOUND SSC 1000mph land speed record attempt.

He was Editor-in-Chief of the world's first *Encyclopedia of Automotive Engineering* to be published in 2013.

Preface

In writing this book, we have aimed it at the needs of both students and practising engineers in the automotive industry. For engineering students, we hope we have provided a sound explanation of the principles behind the design of vehicle powertrain systems. For practising engineers, we have tried to provide a comprehensive introduction to the subject area, which will set the scene for more specialized texts on, for example, engines, transmissions or hybrid electric components.

The book has arisen from our combined teaching experiences at a range of institutions including the Iran University of Science and Technology (IUST), Tehran, and the Universities of Leeds, Sunderland and Cranfield. We have attempted to incorporate two important themes which distinguish our book from other texts:

1. The inclusion of numerous worked examples and the provision of a MATLAB® code for many of the problems.
2. A systems approach to powertrain design – focusing on the integration and interactions of all the components, e.g. engine, transmission final drive, wheels and tyres – in analyzing the overall vehicle performance.

Our experience of teaching engineering students suggests that one of the most useful ways of learning engineering principles is through actually doing problems oneself. Hence, we have tried to provide a wide range of examples together with worked solutions, often with an accompanying MATLAB code. We hope that readers will run these short programmes themselves and modify them to examine other performance issues.

The term 'systems approach' is widely used in engineering but is not always clarified in the particular context. Here, we simply mean that in order to understand vehicle performance, it is necessary to analyze all the powertrain components together and examine how they interact, and how the designer tries to integrate them in a coordinated way. Our experience suggests that there are relatively few texts which deal comprehensively with this critical aspect of integration.

At the time of writing, there is considerable pressure on the automotive industry to minimize energy consumption and reduce global emissions. This has led to a huge upsurge in interest in alternative powertrain systems – and the development of a range of electric and hybrid electric vehicles. However, consumers do not appear to be willing to compromise some of the traditional aspects of vehicle performance, e.g. acceleration, speed, etc. in the interests of overall energy consumption. Drivability remains a key commercial issue and there is a demand for vehicles which are 'fun-to-drive'. Hence, the design challenge continues to involve a compromise between vehicle performance and energy usage. We have tried in this book to provide a comprehensive coverage of both these – often conflicting – aspects of vehicle behaviour.

Vehicle Powertrain Systems is accompanied by a website (www.wiley.com/go/mashadi) housing a solution manual with detailed explanations for the solution methods of more than a hundred exercises in

this book. The solutions of the majority of the problems are carried out in MATLAB environment and the program listings are also provided. In addition to the worked examples of the book itself, the website offers invaluable guidance and understanding to students.

Finally, we would like to thank all our colleagues and friends over the years who have contributed in some way or influenced us in writing this text.

Abbreviations

2WD	2-wheel drive
4WD	4-wheel drive
AC	alternating current
AFR	air-fuel ratio
Ah	amp-hour
AMT	automated manual transmission
AT	automatic transmission
BAS	belted alternator starter
BD	block diagram
BDC	bottom dead centre
BLDC	brushless DC
BMEP	brake mean effective pressure
BMS	battery management system
BSFC	brake specific fuel consumption
CAFE	corporate average fuel economy
CI	compression ignition
CO_2	carbon dioxide
COP	conformity of production
CPP	constant power performance
CSM	charge sustaining mode
CTP	constant torque performance
CVT	continuously variable transmission
DC	direct current
DCT	dual clutch transmission
deg.	degree
DOF	degree of freedom
DOH	degree of hybridization
EC	eddy current
ECU	engine control unit
EFCC	Efficient Fuel Consumption Curve
EGR	exhaust gas recirculation
EM	electric motor
EMS	engine management system
EOP	engine operating point
EPA	Environmental Protection Agency
EREV	extended range electric vehicle
EUDC	extra-urban European driving cycle
EV	electric vehicle

FBD	free body diagram
FC	fuel consumption
FCVs	fuel cell vehicles
FEAD	front engine accessory drive
FEM	finite elements methods
FTP	Federal Test Procedure
FTP	fixed throttle performance
FWD	front wheel drive
GDI	gasoline direct injection
HC	hydrocarbons
HCCI	homogeneous charge compression ignition
HEV	hybrid electric vehicle
IC	internal combustion
ICE	internal combustion engine
IMEP	indicated mean effective pressure
I/O	input/output
ISG	integrated starter-generator
ISO	International Standard Organization
IVT	infinitely variable transmission
kg/J	kilogram per joule
kWh	kW-hour
l	litre
LCV	low carbon vehicle
LS	low speed
MAP	manifold absolute pressure
MC	motor controller
MCU	motor control unit
MG	motor/generator
MPa	mega Pascal
MPD	mechanical power distribution
MPI	multi-point (port) injection
MT	Magic Torque (formula)
MT	manual transmission
NEDC	New European Driving Cycle
NOx	oxides of nitrogen
NRF	no-resistive-force
NVH	noise, vibration and harshness
OOL	optimal operating line
PCP	pedal cycle performance
PGS	planetary gear set
PHEV	plug-in hybrid electric vehicle
PID	proportional integral derivative
PSD	power split device
RMS	root mean square
rpm	revs per minute
RWD	rear wheel drive
SCU	supervisory control unit
SFG	single flow graph
SI	spark-ignition
SOC	state of charge

SPH	series-parallel hybrid
TA	type approval
TAD	torque amplification device
TBI	throttle body injection
TC	torque converter
TDC	top dead centre
THS	Toyota Hybrid System
TPS	throttle position sensor
VVT	variable valve timing
Wh	Watt-hour
WOT	wide-open throttle

Contents