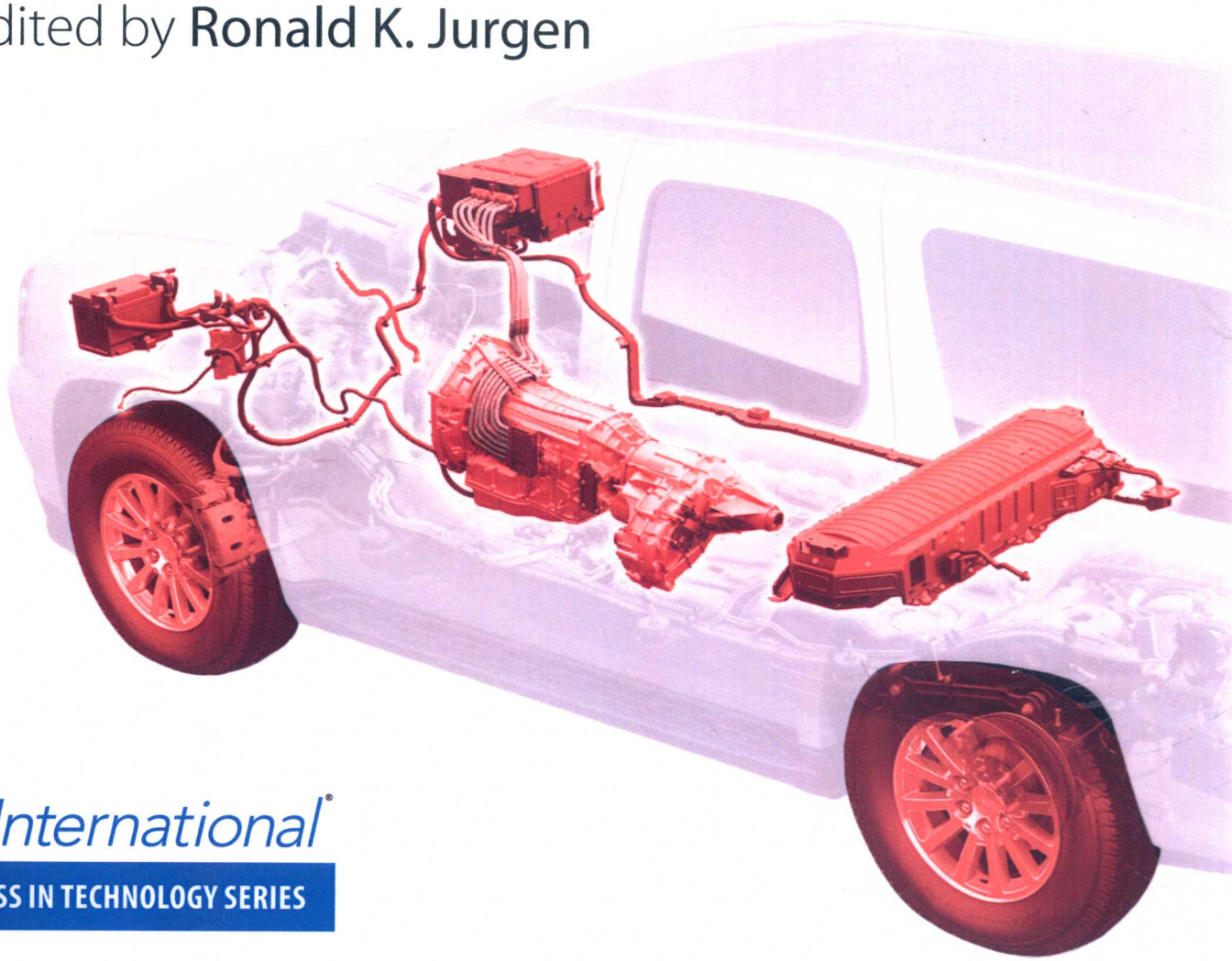
Electric and Hybrid-Electric Vehicles

Braking Systems and NVH Considerations

Edited by **Ronald K. Jurgen**



SAE International®

PROGRESS IN TECHNOLOGY SERIES

Electric and Hybrid-Electric Vehicles – Braking Systems and NVH Considerations

Edited by

Ronald K. Jurgen

Published by
SAE International
400 Commonwealth Drive
Warrendale, PA 15096-0001 USA

Phone: (724) 776-4841
Fax: (724) 776-5760
www.sae.org

PT-143/4

SAE International™

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: 724-776-1615

ISBN 978-0-7680-5720-1 (Volume)
ISBN 978-0-7680-3439-4 (Set)
Library of Congress Catalog Number 2010929147
SAE Order No. PT-143/4

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: 724-776-1615

Visit the SAE Bookstore at
http://store.sae.org

Electric and Hybrid-Electric Vehicles — Braking Systems and NVH Considerations

Other books in this set

Electric and Hybrid-Electric Vehicles – Overviews and Viewpoints
(Product Code: PT-143/1)

Electric and Hybrid-Electric Vehicles – Batteries
(Product Code: PT-143/2)

Electric and Hybrid-Electric Vehicles – Engines and Powertrains
(Product Code: PT-143/3)

Electric and Hybrid Electric Vehicles – Fuel Cell Hybrid EVs
(Product Code: PT-143/5)

Other SAE books of interest

Hybrid Powered Vehicles, Second Edition
By John M. German
(Product Code: T-125)

Hybrid Gasoline-Electric Vehicle Development
By John M. German
(Product Code: PT-117)

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

400 Commonwealth Drive, Warrendale, PA 15096-0001
phone 877-606-7323 *(U.S. and Canada)* **or 724-776-4970** *(outside U.S. and Canada)*
fax 724-776-0790

e-mail: *CustomerService@sae.org*

website: *http://store.sae.org*

TABLE OF CONTENTS

Introduction

EV Braking Systems

NVH Considerations

INTRODUCTION

Introduction

The Growing Surge in Electric Vehicle Activity

Ronald K. Jurgen, Editor

After a relatively slow start in recent years, production of and planning for new electric vehicles (EVs)—gasoline hybrid-electric vehicles (HEVs), plug-in hybrid-electric vehicles (PHEVs), extended-range electric vehicles (E-REVs), fuel-cell hybrid vehicles (FCVs), and battery-electric vehicles (BEVs)—is gaining momentum worldwide. The increased activity is taking place in new car model introductions in price ranges from relatively inexpensive to definitely expensive. Activity is also on the rise in such areas as batteries, powertrains, and plug-in infrastructures.

New and planned OEM offerings

Here are just a few among many examples of increased activity in new and planned OEM offerings:

- Toyota is planning a widespread release in 2012 of a PHEV car with a powerful lithium-ion battery.[1] The car will travel 14.5 miles as an electric vehicle on a single charge before a regular gas-electric hybrid system kicks in. Overall mileage is 134 mpg. Charging time is about 100 minutes.
- At a conference on PHEVs held in Detroit, Michigan, Oct. 19-21, 2009,[2] Ford announced plans to bring a battery-electric Transit Connect commercial van to market in 2010, a battery-electric Ford Focus compact car in 2011, and third-generation hybrids and plug-in hybrids later. China's Suzhou Phylion Battery Co. is producing two types of cells for automotive applications: an 8-A·h high-power cell with a power density of 1700 W/kg for hybrid vehicles and a 40-A·h high-energy cell with an energy density of 105 W·h/kg for PHEVs and battery-electric vehicles.
- The Nissan Motor Company plans to produce 50,000 Leaf all-electric, front-wheel-drive, five-door hatchbacks to be marketed in Japan and the U.S. in the latter part of 2010.[3] A dedicated EV platform carries a 24-kW·h lithium-ion battery pack on an additional frame structure under the cabin floor within the wheelbase. Total output is said to be 90 kW plus an average voltage of 345 V, with energy density of 140 W·h/kg and power density of 2.5 kW/kg. The Leaf has two charging ports: one for dc 50-kW quick charge that takes 30 min for an 80% charge, and the other for ac home charge 200/100 V (Japan) that is said to take less than 8 h at 200 V. Maximum speed is 140 km/h (87 mph) and single-charge range is 160 km (100 mi)-plus on the U.S. LA4 test cycle.

Pushing the envelope

"Lithium battery technology is finally making its way into production hybrids and planned EVs, but improvements are needed."[4] The Mercedes-Benz S400 hybrid uses Li-ion batteries as does the Tesla BEV roadster. Problem areas for the batteries include power output decline at very low temperatures and life span reduction at very high temperatures. But in BEVs, batteries charge only about 3000 times in a decade of service and use about 80% of their cells' capacity. "The eventual goal for durability should be

more than 12 years of use over a distance of 150,000 mi (240,000 km),"according to Joachim Fetzer of SB LiMotive, a joint battery venture between Samsung and Bosch.

Other problem areas and possible solutions include:

- EVs do not produce enough waste heat to warm up the interior.[5] The solution to the problem depends on the overall concept and drivetrain. In the Rinspeed iChange EV concept car, the supplier has integrated two heating systems. A high-voltage air heater is active during short trips and city traffic. It transforms 580-V onboard voltage into heat with a variable resistor with a positive coefficient of temperature. For longer trips there is a fuel-powered heater that consumes a maximum of 0.43 L (0.11 gal) per hour and works at 84% efficiency. A possible drawback? The driver has to refill a 3.5-L (0.9-gal) fuel tank hidden behind the car's license plate.
- The quietness of BEVs and hybrids has a serious downside in that pedestrians and bicyclists are less likely to hear them coming and neglect getting out of their way.[6] To counter this problem, Nissan, Fisker, and other OEMs are equipping models with high-tech noises that warn of their cars' presences.
- PHEVs need easy access to recharging facilities, not just at home, but on the road. Providing such an infrastructure is a formidable problem, but there is progress being made worldwide. In 2008, Israel became the first country and the Renault-Nissan Alliance became the first automakers to embrace Better Place's model of building an open-network infrastructure to enable mass EV adoption.[7] In Denmark, the biggest Danish power company is working with Better Place in a $100 million program to wire the country with charging poles as well as service stations to change out batteries in minutes.[8] The Danish government offers a minimum $40,000 tax break on each new EV plus free parking in downtown Copenhagen. And in San Francisco, the building code is due to be revised so that new structures will be wired for car chargers.

Potential delaying factors

A study on PHEVs by the National Research Council, released on December 14, 2009, concludes that PHEVs are unlikely to arrive in meaningful numbers for a few more decades.[9] The report also stressed that the new generation of plug-in hybrids could require hundreds of billions of dollars in government subsidies to take off. Other conclusions in the study are:

- PHEVs could number 40 million by 2030 if rapid progress is made in battery technology (with large government incentives), but a more realistic number would be about 13 million vehicles.
- Optimistically, 6.5 million PHEVs could be sold annually in the U.S. by 2030.
- A PHEV capable of running for 40 miles on electricity would cost $18,000 more than a similar conventional car, including a $14,000 battery pack.
- In order for PHEVs to reach large numbers of U.S. households, there would need to be more recharging outlets and other infrastructure improvements.

Despite the long time frame cited in these reports, there are signs of accelerating EV programs. For example, another report stated that the number of HEVs, PHEVs and BEV programs currently approved for production world-wide is growing steadily year-on-year.[10] And some recent examples of ambitious public policy initiatives aimed at creating low-carbon transportation include:

- China's vow to be a leading hybrid and EV producer within five years, supported by billions in funding for battery technologies and charging infrastructure
- Germany's plan to put 1 million electrified vehicles on the road by 2020
- President Obama's push for 1 million PHEVs and EVs in use by 2015 bolstered by $2.4 billion in Department of Energy development funds."

Another article[11] cites the Department of Energy's "slashing the federal budget request for hydrogen fuel-cell research in 2010 by $100 million to $68 million . . . Proponents of hydrogen research have since lobbied strongly to restore government support. Congress is considering likely votes to reinstate all of the funding for hydrogen and fuel-cell research . . . The stimulus bill passed earlier this year – the American Recovery and Reinvestment Act – provides $42 million for fuel-cell and hydrogen research."

Insofar as the savings to buyers of electric cars is concerned, a report by Intellichoice.com states that most of the 51 hybrid and clean-diesel vehicles on sale in the United States will pay for themselves in five years or less despite higher purchase price,[12] and Jon Wellinghoff, the U.S. power-grid chief, is cited in another article[13] as saying that electric cars could net their owners $1500 a year in paybacks when their batteries are connected to the power grid.

About this book

This book, *EV Braking Systems and NVH Considerations*, is one volume in a five-volume EV series. (Other volumes in the series are *Overviews and Viewpoints*, *Batteries*, *Engines and Powertrains*, and *Fuel-Cell Hybrid EVs)*. It contains eight papers published from 2008-2010.

Regenerative braking in hybrid and electric vehicles uses the electric motor as a generator to convert kinetic energy of the moving vehicle into electric energy when decelerating the vehicle. Special brake systems are needed to take full advantage of this technique. The three papers on braking in this book discuss various approaches to regenerative braking. The following are quotes from those papers.

- "This article describes the design of the specific regenerative brake system developed by Continental for different hybrid vehicles which went into series production in summer 2008 in the U.S. The system layout and the components are shown. Specific emphasis is put on general issues involved with regenerative brakes, and control and fail-safe of the specific system. Experimental data from the vehicles brought into series production prove the performance of the system." (2009-01-1217)
- "This paper presents the design of a novel brake system, namely Auxiliary Pressurized Hybrid Brake System, which enables energy recovery and a safe transition from regenerative brake to hydraulic brake with minimum intervention to the existing hydraulic brake line of the second-generation Ford Transit hybrid-electric van." (2009-01-2876)
- "In this paper, we present a scheme for the modeling and control of regenerative braking. The whole system is considered as a dual-actuator system which consists of the air-over-hydraulic brake system and the generator. The models of two actuators are proposed first. A model validation is also carried out for the model of the AOH brake system. Based on the proposed models, we provide a control scheme for braking torque tracking, in which a constant braking torque is distributed to the AOH brake system and dynamic torque tracking is designed for the generator." (2008-01-1569)

In the Noise-Vibration-Harshness (NVH) section, four papers discuss various means for reducing NVH, while a fifth discusses the need to add noise to EVs in order to warn pedestrians and cyclists of their presence. Advocates for the blind have teamed up to draft proposed legislation as part of the Motor Vehicle Safety Act of 2010 to require hybrid and electric vehicles to emit a specified level of sound at lower speeds.[14] The sound could take a variety of forms. For example, Lotus's concept electric-powered version of its Evora sports coupe offers four artificial engine sounds that play through the audio system's speakers. And one of BMW's developmental Active Sound Design system offerings makes a diesel engine sound sporty.

The following are quotes from these papers.

- "The big challenge for good NVH of a Range Extender is the control of noise and vibration at low engine orders: noise arising from the exhaust and intake system, vibration arising from unbalanced masses of the internal combustion engine. With the choice of a rotary piston engine for RE application, the problem of unbalanced mass vibration is minimized. However, the excitation of exhaust and intake noise is high with the piston-ported rotary engine requiring extensive control measures. This includes not only strong control technologies and hardware measures, but also clever RE operation strategies for different vehicle speed ranges with at least two engine speed-load points and appropriate transitions. It can also include active noise cancellation technologies." (2010-01-1404)
- "The acoustic development process, as many other processes in vehicle engineering, follows the so-called 'V-Model.' Coming from overall subjective and objective N&V-targets, which have to be defined at the very beginning of a vehicle development project, it is essential to break down these targets to system (and even component) level in order to be able to handle the work split between complete vehicle responsibility and suppliers. In the development process these defined targets have to be reached and validated coming from system level to full vehicle level." (2010-01-1403)
- "For hybrid and electrical vehicles . . . new challenges will occur with every new vehicle which will be developed. The currently high number of concepts and strategies, as with any new technology, will converge to a lower number of proven concepts. Main issues for advanced development on N&V in order to support the emergence of Hybrid and Electric Drivelines will be psychoacoustic investigations, enhancement of the frequency range of current simulation methods, co-determination of control algorithms, and a massive application of optimization tools." (2010-01-1403)
- "The blind community is concerned that vehicles are becoming too quiet and unsafe for pedestrians. With vehicle manufacturers successfully working to develop quieter vehicles and the emergence of a new class of quiet hybrid and electric vehicles, this concern from the blind community will continue to increase. The basis of the concern is that a blind person uses acoustic cues to determine the location and speed of vehicles to avoid dangerous situations." (2009-01-2189)
- "Control of annoying noises such as buzzes, squeaks, and rattles (BSRs) is particularly important for complex products such as automobiles. This importance has become even more significant as electric vehicles become more popular, eliminating much of the ambient background vehicle noise. This paper introduces the application of spherical beamforming technology to BSR testing and

provides the results showing the localization accuracy of a rigid spherical array system in a vehicle cabin." (2009-01-2114)

- "This paper demonstrated the use of metrics and methods such as vibration dose value and energy spectral density analyses, and multi-body systems-based processes to characterize and refine the internal combustion engine start/stop behavior. In addition, the application of advanced time-domain based transfer path techniques such as vehicle interior noise simulation to understand and solve challenging HEV noise problems was demonstrated. The presented case studies provide a discussion of the root cause of the specific NVH issues, objective quantification methods, and development of appropriate refinement-oriented countermeasures." (2009-01-2085)

References

1. Hiroko Tabuchi, "As Rivals Gain, Toyota Announces Plug-In Hybrid Prius," the *New York Times*, p. B5, Dec. 15, 2009.
2. Kami Buchholz, "The High Cost of Plugging In," *Automotive Engineering International*, pp. 17-18, Dec. 2009.
3. Jack Yamaguchi, "Nissan Leaf," *Automotive Engineering International*, pp. 32-34, Oct. 2009.
4. Dan Carney, "Lithium battery bonanza," *Automotive Engineering International*, pp. 30-32, Dec. 2009.
5. Jörg Christoffel, "Thermal management challenges in EVs," *Automotive Engineering International*, p. 32, Nov. 2009.
6. Stephen Mihn, "Artificial Car Noise," *The New York Times Magazine*, p. 28, Dec. 13, 2009.
7. Kevin Jost, "Vehicles and Infrastructure," *Automotive Engineering International*, p. 6, Dec. 2009.
8. Nelson D. Schwartz, "In Denmark, Ambitious Plan for Electric Cars," *New York Times*, pp. A1-A3, Dec. 2, 2009.
9. Jad Mouawad and Kate Galbraith, "Study says big impact of the plug-in hybrid will be decades away," *The New York Times*, Dec. 15, 2009.
10. Lindsay Brooke, *Automotive Engineering International*, p. 21, Oct. 2009.
11. Steven Ashley, "Congress looks with favor on fuel-cell funding," *Automotive Engineering International*, p. 45, Oct. 2009.
12. Tom Incantalupo, "Report finds most hybrid cars pay off in 5 years," Fort Lauderdale *Sun-Sentinel*, Aug. 23, 2009.
13. Steve Gelsi, "Electric cars plugged by federal regulator," Fort Lauderdale *Sun-Sentinel,* Oct. 18, 2009.
14. Jim Gorzelany, "Make Some Noise," Fort Lauderdale *Sun-Sentinel*, Aug. 14, 2010.

o o o o o o o o o

This book is dedicated to my friend Richard Keaton.

EV BRAKING SYSTEMS