AWD Efficiencies (Part 1)

Session Code: AWDS100
Room Galilee Ballroom

Steve Wesoloski, Cosworth LLC

Organizers -

10:30 a.m. ORAL ONLY
High Efficient Pre-Emptive On-demand AWD Transfer Case

Ever more stringent, worldwide light-vehicle fuel economy and emission regulations are converging design focus on finding new solutions to maximize efficiencies of All Wheel-Drive systems. An electro-hydraulic actuated on-demand Transfer Case has been developed for RWD based platforms (SOP in 2015) which provides significant efficiency improvements in a compact and torque dense package while delivering the required pre-emptive AWD performance. The design includes several innovative features such as pumpless lubrication; active oil sump level control and a high efficient 2WD mode in conjunction with a front axle disconnect system.

This presentation will provide an overview of these key features including operating principle as wells as vehicle and bench data.

Christopher J. Kowalsky, BorgWarner TorqTransfer Systems

11:00 a.m. ORAL ONLY
Friction Stir Welding of Gearbox Housings and Axle Drives for Reduced Weight and Cost

Today¿s automotive industry is more than ever struggling to lower production costs and reduce weight. The main reasons for that are legal regulations regarding the acceptable CO2 emissions on the one hand and - driven by consistent growing gas prices - the increasing demand of the end customers to purchase more fuel-efficient vehicles without compromising riding comfort or safety.

One innovative approach to reduce the weight of a vehicle from the Powertrain¿s point of view is to replace the chunky bolt connection of the (for machining and assembly reasons divided) gear box housings with a lighter and more compact joining method. A joining process which can fulfill the mentioned requirements and that also shows economic advantages is the so called ¿Friction Stir Welding¿ process. This welding technology produces a firmly bonded metallic joint of Aluminum die cast housing parts with only insignificant temperature influence and low loads during processing. Bolted connections were considered state of the art for decades but the past has shown that in many cases replacing bolt connections with welding processes is both feasible and useful. The best example in this context is a shaft to hub connection between a spur-, helical- or crown- gear and a shaft or differential housing, which today is usually done by laser or electron beam welding. The main focus here is also to reduce weight, space and cost.

This speech will give an introduction to this unique joining method and show the different development steps which were necessary to apply Friction Stir Welding to a heavy loaded Rear Axle Drive housing. In addition to that the achievable savings in terms of weight and cost will be discussed. Pictures and a video will illustrate the feasibility of the Friction Stir Welding process to be used in this new application field.

Finally, the pros and cons will be summarized and a direct comparison between a Bolted and Friction Stir welded variant will be drawn.

Alexander Dietrich, Heinz Klampfl PhD, Magna Powertrain
11:30 a.m. ORAL ONLY Methods to model, design, and develop an electrified vehicle powertrain system

This article will describe a method to model, design, and develop an electrified vehicle driveline system architecture and quantify the benefits it has on fuel economy, performance, and implementation. The size, power, and layout of the electrified system has to be derived by considering the vehicle driving cycles for the segment of vehicle being electrified. In order to select the best architecture, simulation of various hybrid electric powertrains are analyzed using AVL CRUISE and AVL VSM under different control methods to determine the best balance of performance, functionality, and cost. To keep cost down and allow for modularity, the electrified system is designed to be self-contained and compact permitting a common architecture to be utilized across many vehicle platforms. With this method, many types of electrified drivetrains can be achieved ranging from hybrid assist to full EV. To qualify our simulation, dynamometer testing using AVL's VSM embedded in PUMA dynamometer controls as well as on-road testing was performed.

Methods for selecting and simulating hybrid electric powertrain architecture and the associated control systems' performance and functionality.
- Study of market demands and trends
  - Voice of the customer
- AVL CRUISE modeling for performance and fuel economy
  - Energy generation and re-generation
- CARSIM modeling for vehicle stability and handling and chassis dynamics

Hardware design and vehicle integration
- Self-contained compact design
- Scalable for use as hybrid assist, AWD, or pure EV application
- Active Torque Vectoring

Dynamometer testing using AVL's VSM imbedded PUMA and on road verification
- Dynamometer testing for controls development
- Independent torque control calibration for eAxle
- High level vehicle response
- On road and dynamometer calibration and correlation to vehicle simulation

Bruce Falls, AVL; Kevin Ledford, Linamar Driveline Systems Group

Tuesday, October 14

AWD Efficiencies (Part 2)

Session Code: AWDS101

Room Galilee Ballroom Session Time: 1:00 p.m.

Organizers - Tom Mockeridge, General Motors Co.
1:00 p.m.  ORAL ONLY  First Year with a Disconnecting All Wheel Drive System
The 2014 Jeep Cherokee, which contains AAM’s EcoTrac disconnecting all wheel drive system, is the first system of its type available for sale to the public, entering the market in September of 2013. Disconnecting all wheel drive systems have garnered significant interest from most OEM’s, as selling conventional all wheel drive vehicles will become more difficult in the run up to the 2025 mileage requirements.
This presentation will review some of the more significant events over the course of the first year, including a synopsis of development challenges, vehicle reviews, real-world mileage results, and upcoming next generation enhancements.

John C. Hibbler, American Axle & Mfg Inc.

1:30 p.m.  ORAL ONLY  Maximizing Performance and Optimizing Fuel Economy through the Use of Mechatronics and Systems Engineering Methodologies
According to IHS Automotive, nearly one in every four vehicles sold in the U.S. in 2013 were equipped with All-Wheel Drive, and the numbers continue to climb. Developing technology that balances performance demands of consumers with efficiency regulations placed on vehicle manufacturers will lead to winning cars and trucks. Dana will present findings from a systems engineering perspective on how lessons learned from its off-highway business unit are being leveraged to address performance and fuel economy challenges, including clutch disconnect technology that automatically disengages at critical moments, while enabling front-wheel drive only when the demand for AWD is not needed. This presentation will explore architectures and approaches for ensuring the highest levels of performance and efficiency.

Mark Versteyhe, Dana

2:00 p.m.  ORAL ONLY  Modelling and Simulation of Competitive AWD Systems (eAWD, Disconnect, and Conventional)
With the competitive requirements of selling an AWD system in a fuel economy conscious market, modelling and simulation aids in the assessment of the most value added alternatives. The intent of this presentation is to define a method for modelling an AWD system with both fuel economy and performance in mind. Further, we will utilize AVL-CRUISE too highlight some findings and some of the benefits to an eAWD, conventional, and disconnect systems.

Nathan Schaly, Linamar

Tuesday, October 14

AWD Efficiencies (Part 3)
Session Code:  AWDS102
Room Galilee Ballroom  Session Time:  3:00 p.m.
Organizers -  Joe Palazzolo, GKN Driveline North America Inc.

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The presentation discusses the simulation-driven product design process required to arrive at the right, robust, efficient motor design through multi-physics modeling using a top-down approach to E-Drive design optimization. Detailed examples applying CAE tools in e-drive optimization by design analysis will be presented.

Major vehicle manufacturers around the world are developing increasing numbers of electric and hybrid vehicle (EV/HEV) powertrain architectures to meet CO2 reduction targets, stringent fuel consumption regulations and customer demands for greener transportation. These EV/HEV architectures range from hybrids to electric vehicles and extended-range plug-in electric vehicles. Electrification requirements are being developed to provide optimum performance in a wide variety of drive cycles. A key component of all these vehicle architectures to achieve powertrain targets is the electrical machine.

The process of developing an optimal, robust and efficient electrical machine to meet these requirements involves complex engineering for the electromagnetic design, thermal-cooling, mechanical stress, and minimizing NVH (noise, vibration and harshness) through modeling and simulation.

A simulation-driven product design process yields accurate loss and efficiency maps as well as predictions for second order phenomena such as torque ripple & NVH. High fidelity simulation considers complex 3-D effects, such as end-winding inductance and core losses. With a comprehensive multi-physics modeling approach, the cooling system and magnetics are optimized together as a part of the design to meet cost and performance targets. The process also leverages the advantages of high-performance computing and parametric variables to perform extensive parametric optimization studies. In one design case, Magna reduced magnet content by 20 percent and met target efficiency over the required operating range.

End results of this approach are vehicles with powertrain performance satisfying OEM and customer alike with industry leading performance metrics for MPGe, Watt-hr/mile and range.

Brian Peaslee, Magna Powertrain
Future AWD Disconnect System

The all-new 2015 Jeep Renegade debuts a fuel efficient disconnecting AWD driveline system. The vehicle vision demanded best-in-class trail rated off-road performance moving the Jeep DNA into the B segment for the first time. Such high performance in a tight environment necessitated innovative technologies:

- High strength PTU gear design
- Optimised PTU and propshaft interface
- Electro-mechanical dog clutch PTU disconnect actuator
- Electro-mechanical RDM side mounted clutch actuation

This modular AWD architecture lends itself to a wide array of vehicle integration opportunities ranging from fuel efficient sedans to trail-rated SUVs. The architecture has sufficient design flexibility to facilitate scalable torque capacities that target specific applications and controls strategies that are adaptable to enable brand-specific performance. Particular system integration highlights to be reviewed in detail include:

- Packaging flexibility for small segment applications
- Customer selectable usage profiles
- Automated transitions between modes (FWD and AWD)
- Tuning flexibility
- System Validation
- Trail rated off-road performance

Joseph E. Kubina, Chrysler Group LLC; Christian Carlondo, GKN Viscodrive GmbH

Analysis on Frictional Behavior of Planetary Gear Type Torque-Sensing LSD for AWD

Recently, in the field of full-time AWD specification exclusively for Hybrid vehicles, with higher fuel efficiency of Hybrid as well as improvement on driving stability and regeneration efficiency brought by AWD, further growth is expected in the future.

The gear type torque-sensing Limited Slip Differential (LSD) is described in this study, which features the Limited Slip Differential in addition to general differential functions. Mainly, the type targeted for center differential of AWD is discussed in this paper.

Its specific feature is that how the planetary gear is kept in the housing; the planetary gear is stored in the bore of the housing so that it can rotate by itself. Engine torque input to the housing is distributed to the sun gear and the internal gear via the planetary gear. In order to limit the slip, friction force generated from the surface of the washer and the outer circumference of the planetary gear is mainly used.

The gear type torque-sensing LSD may cause a differential rotation with producing some friction inside products depending on driving conditions. In this case, it is required not only to prevent stick-slip but also to make the friction smooth on sliding surfaces. For an approach to this issue, micro-roughness on the sliding surface of the planetary gear circumference is given as one example of damping technologies (prevention of self-excited vibration). The micro-roughness given to the planetary gear circumference avoids an excessive oil film which comes with sliding speed increase.

In addition, a carbon based hard coating to the planetary gear is introduced to ensure abrasion and seizure resistances which have trade off relationships with the micro-roughness. As noted above, by applying the micro-roughness and the carbon based hard coating to the outer circumference of the planetary gear, reliability and quietness of the gear type torque-sensing LSD have been improved dramatically.

Junji Ando, JTEKT CORPORATION
Tuesday, October 14

Opening Ceremony & Keynote Address
Session Code:  AWDS103
Room Garden Gallery                  Session Time:  8:00 a.m.

Time       Paper No.       Title

8:00 a.m.   ORAL ONLY     Opening Ceremony
Brandon S. Vivian, General Motors Co.

8:10 a.m.   ORAL ONLY     Keynote Address: Meeting 2025 Regulations ¿ A Governmental Perspective
Michael Olechiw, US Environmental Protection Agency

Tuesday, October 14

Executive Panel: Meeting 2025 Regulations ¿ An Industry Perspective
Session Code:  AWDSPANEL
Room Garden Gallery                  Session Time:  8:30 a.m.

These esteemed panelists have been assembled to share their views on how regulations impact the industry and the systems that they engineer, the complexities of these systems, customers¿ acceptance of new technology, and other challenges being faced.

Moderators -   Daniel M. Hancock, DMH Strategic Consulting LLC
Panelists -    Kevin Carlstrom, Eaton; Roger Clark, GM Engineering; Michael P. Kirk, Chrysler Group LLC; Donald Remboski, Dana Holding Corporation; Craig Renneker, Ford Motor Co.;

Tuesday, October 14

SAE Standards Update
Session Code:  AWDS104
Room Garden Gallery                  Session Time:  9:45 a.m.

Time       Paper No.       Title

9:45 a.m.   ORAL ONLY     Drivelines
Robert Mangan, Link Engineering Co.

9:53 a.m.   ORAL ONLY     Transmission
Abe Khalil, SPX Filtran

Wednesday, October 15

Electrification & Performance (Part 1)
Session Code:  AWDS200
Room Galilee Ballroom                Session Time:  8:00 a.m.

Organizers -   Benjamin Dale Meikle, Eaton

Time       Paper No.       Title
Enhanced Wheel Slip Control for Electric Vehicles with Four-Individual-Wheel Drive

Compared to conventional anti-lock braking systems based on friction brakes and pressure release valves, four-individual-wheel drive with independent electric motors (rule-based bang-bang ABS controller, used on 99% of the cars and since 1985), in which ABS modulation is performed entirely via generative torque control, taking advantage of fast motor response compared to `slow¿ hydraulic friction brakes, allows for a significantly improved braking control action and thus significant reduction of braking distance. Although the availability of a high power density (240 kW) energy storage medium, special research effort has been made to develop an adequate brake blending function. With similar principles applied in the case of the anti-lock braking system, a traction control system is developed allowing for reduced vehicle acceleration time. Presented are an introduction to the methods used and the results showing a clear and valid prove of concept via experimental demonstration on track. The research leading to these results was carried out during the E-VECTOORC project (European Union Seventh Framework Programme FP7/2007-2013) in close collaboration with Jaguar Cars Limited (United Kingdom), Land Rover (United Kingdom), SKODA Auto (Czech Republic), TRW Automotive (Germany), Inverto (Belgium), Technische Universität Ilmenau (Germany), University of Surrey (United Kingdom), Instituto Tecnologico de Aragon (Spain), Virtual Vehicle Research Center (Austria) and Fundación Cidaut (Spain).

Dirk Steenbeke, Johan Theunissen, Flanders Drive
Twin Motor Unit of Sport Hybrid SH-AWD

Hybrid-AWD vehicle which drive the main driving wheels by engine and transmission and drive the sub driving wheels by electric motor are spreading. As a technical problem about a motor, it is known that output torque declines at high rotation speed and there is a upper limit for the rotation speed according to a strength limit.

In order to solve these subject, we developed original Twin Motor Unit(TMU) for hybrid-AWD vehicle. The composition of the TMU is as follows.

* Two motors arranged at the left and right side to drive both axle shaft independently.
* Double pinion planetary reduction gears equipped with One Way Clutch(OWC) and brake arranged in the center.

By carrying out independent control of the motor on either side, both all-weather traction by all wheel drive control and the dynamic handling by right-and-left torque vectoring control are realized. Disconnecting and connecting motors are performed by OWC and the brake which is controlled by the oil pressure generated by the electric oil pump. The ring gear is fixed by OWC for the case of motor outputs positive torque, and by brake for the case of motor outputs negative torque. In a vehicle high speed condition, motor rotation speed can keep low by turning off brake oil pressure and the motor drive torque because motors are disconnected from axle shaft.

The feature of the TMU is that right-and-left torque vectoring is possible also in this motor disconnected state. With the ring gear is rotating by the input from axle shaft, if the motor of one side is driven, the torque which is going to stop ring gear rotation will act and the motor of the opposite side will be turned as a result. At this time, if the motor of the opposite side outputs the torque of the same size to an opposite direction, the torque concerning the ring gear will be in a right-and-left equilibrium situation, and the rotation speed of the ring gear becomes stable. In this state, motor torque is outputted to an axle shaft through reduction gears, and it is exactly in the torque vectoring state outputted to the right-and-left opposite direction. Motor is disconnected from the axle shaft, and can be used at low rotation speed, it becomes possible to carry out right-and-left torque vectoring control in all the vehicle speed ranges, without being subject to the influence of a motor output torque decline.

We applied this feature to real vehicle and confirmed that vehicle stability improved by performing right-and-left torque vectoring which generates the yaw-moment of an opposite direction with turning at the high speed condition. By development of the TMU, we could introduce efficient and compact Hybrid-AWD system that enhance both all-weather traction and dynamic handling on the high level.

Takabumi Suzuki, Honda

High Performance Electric Front Axle (eAxle) For The Porsche 918 Spyder

The Porsche 918 Spyder is the world’s first super sports car designed as a plug-in hybrid. It represents future sports car technology combining lowest fuel consumption and ultimate driving dynamics and performance.

Joe Palazzolo, GKN Driveline North America Inc.; Anja Haniche, GKN Driveline GmbH
FWD eLSD for Efficiency, Performance and Fun-To-Drive

Consumers continue to expect increasing levels of driving security and performance while vehicle manufactures must balance the ever increasing fuel economy and emissions requirements. Electronic Limited-Slip Differential (eLSD) greatly enhances vehicle traction, stability and cornering performance on a FWD vehicle while delivering a secure fun-to-drive experience beyond what is possible with conventional brake-based intervention systems.

This enhanced driving performance approaches that of AWD, but with reduced cost, weight, and fuel consumption. This technology recently launched on the VW Golf GTi (Performance Pack) as the world’s first application of eLSD on a FWD vehicle.

This presentation provides an overview of the operating principle as well as the vehicle system integration. In addition vehicle traction, handling and stability performance will be reviewed as well as contrasting AWD performance. A demonstrator vehicle is planned for the SAE Ride & Drive event.

John Barlage, BorgWarner TorqTransfer Systems

Benefits and Opportunities with Electric Rear Axle Hybrid Drive Technology

Background: Hybridization of vehicles is constantly gaining more attention. The main focus of hybridization has been improved fuel economy, but electric motors have further advantages over combustion engines of controllability, torque accuracy and response time. These capabilities can be used to improve vehicle response, drivability and refinement; giving the customer clear added value.

Placing the e-machine such that it drives wheels directly in a P4, secondary axle configuration, gives the opportunity to maximize the brake energy that is recuperated. Hybridization on the secondary axle (P4) gives the additional benefit of all-wheel drive apart from keeping the front axle installation the same as for non-hybrid vehicles.

The e-AAM P4 hybrid solution has an additional feature of torque vectoring, meaning that the e-machine can be used to enhance lateral stability and cornering agility. This aspect will also be explored in the presentation.

Hybridization on the secondary axle with torque vectoring option provides the vehicle manufacturer with significant advantages compared to other parallel hybrid options such as:

- Maximize the fuel economy by maximum recuperation of the brake energy
- Standard front engine installation
- Improved acceleration, in particular during over-taking
- Improved drivability
- Enhanced lateral stability and cornering agility in torque vectoring mode

Mikael Larsson, AAM
Dual Electric Motor Drivetrain

For the rapidly emerging electric drive market, American Challenge Technologies Inc. (ACT) has developed their Dual Motor Transaxle (DMT). This dual electric motor drivetrain is a modular design that can be utilized for front, rear, or all-wheel drive applications ranging from cars to medium-duty trucks. Patent number US 8,276,693 B2 has been granted.

ACT’s presentation will cover concept, testing and design details, beginning with its flexible packaging. Two REMY HVH250 motors and drive components are contained in an aluminum housing, so they are protected from environmental elements.

Each motor drives a cogged belt which in turn drives one axle. This eliminates the differential, while proprietary ACT software vectors the motors individually to deliver traction control along with vehicle stability system integration. This simple and very cost-effective design offers 98-99 percent power transfer efficiency and 100,000 miles minimum drive belt life.

DMT is rated for vehicles ranging from 5000 to 13000 GVWR, with axle torque ratings ranging from 2100 to 5000Nm. With scalable motor options, DMT delivers up to 180-plus kW of continuous power and peak power ranges up to 320 kW. DMT makes an excellent fit in urban delivery trucks since electric motors are ideally suited for stop and go driving. Plus there’s the added benefit of regenerative braking.

The DMT concept has also been designed for live axle applications that can be used for retrofitting existing vehicles, in addition to new models. DMT is also compatible with performance applications. ACT is supplying a unit to Kepler Motors for use in their MOTION supercar. This all-wheel drive mid-engine car is powered by a 700 horsepower 3.5L twin turbo V6. The DMT is electronically integrated into the drivetrain and is calibrated to deliver an additional 250 horsepower to the front wheels.

Russ Wicks, American Challenge Technologies Inc.

In-Wheel Motor Technology

The concept of having an individual in-wheel motor driving the wheels of a vehicle is not a new idea. An electric vehicle propelled by two in-wheel motors was designed by Ferdinand Porsche for the 1900 World’s Fair in Paris. With a top speed of over 35mph, the ‘System Lohner-Porsche’ went on to set several Austrian speed records of the day, but as internal combustion engines grew in popularity the concept was largely ignored for the following century.

With today's sophisticated electronics and controls coupled with lightweight materials, in-wheel motor technology is now commercially viable and available for modern cars, trucks, crossovers and vans. In-wheel motors enable new electrified powertrains that can address the need for improved efficiency, higher torque and more precise control for superior vehicle dynamics and they have the versatility and packaging simplicity to be applied to a wide variety of vehicles and drivetrain configurations.

Ken Stewart will outline what it takes to develop this new technology, overcome the barriers to acceptance and bring this remarkable value proposition to the commercial automotive market.

Kenneth Stewart, Protean Electric
Session Code: AWDS202  
Room Galilee Ballroom  
Organizers - Joseph Lemieux, IAV Automotive Engineering Inc.

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<td>Mechatronics for use in Disconnecting Driveline Systems</td>
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All Wheel Drive (AWD) systems continue to be a feature desired by many consumers. The improved vehicle dynamics and enhanced vehicle control of such systems notwithstanding, tightening efficiency regulations will place increasing pressure on both original equipment manufacturers and system suppliers to provide AWD benefits while simultaneously reducing any detriments. Advanced AWD systems, both those on the market now and those coming to market in the next few design cycles, will place a premium on enabling efficiency, driver control, and complete transparency of operation. The continuing development of the mechanical/electrical/electronic discipline of mechatronics will be key to this future development. The need to provide these features for even the lightest weight and lowest costs systems will continue to drive development.

Peyman Moradshahi, American Axle & Mfg Inc.

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Sophisticated state of the art drivelines with various intelligent control units (xCU) need to be calibrated and tested stand-alone as well as in interaction. Today the majority of this work is still carried out with prototype vehicles on test tracks. Moving prototype vehicle tests from the road into the lab is key in achieving shorter development times and saving development cost. Such kind of frontloading requires a modular and powerful simulation of all vehicle components, test track and driver in steady state and dynamic operation. The described HIL (Hardware In the Loop) high performance driveline dyno uses driveline components and models from the engine to wheel ends. The EBCM (Electronic Brake Controller Module) was built to be able to do real time vehicle maneuvers and NVH testing. This test setup can emulate any road surface, grade and vehicle inertias such as wheels, engine as close to reality as possible. This test set-up will be used to test, validate and calibrate complete driveline system. Beside dynamic real-world maneuverers also typical NVH testing is possible.

The test bed contains low inertia high performance PMM dynos to simulate the road load at each individual wheel and also as prime mover at the input to simulate a combustion engine. The modular design allows flexible testing of driveline components as well as complete powertrain (front-, rear-, all-wheel drive).

Tom Mockeridge, General Motors Co.
Hierarchical Coordination Control of Driving Force Power Steering and Direct Yaw Moment for 4WD Electric Vehicle with In-Wheel Motors

For 4WD electric vehicle with in-wheel motors, a variety of dynamics control functions can be easily implemented by controlling the driving torque of each motor independently. Driving force power steering system (DFPS) is a novel assisted steering technology, which is proposed based on the characteristics of independent control of steering wheels' driving torque. Chassis motion control like direct moment yaw control can be easily realized due to the advantage of 4WD electric vehicle. For the coordinated control problem of driving force power steering system and direct yaw moment control (DYC), an integrated control algorithm is proposed in this paper. DFPS model controller and DYC model controller were designed separately, and an upper coordination controller was set up based on an idea of hierarchical control. A reference model was designed to determine the expected targets. According to the signal from sensors and expected targets, the upper controller calculated the driving torque of each wheel. A simulation test was performed to verify the algorithm. The simulation results show that the vehicle's yaw rate can follow the reference yaw rate effectively, and hierarchical coordinating control algorithm can improve the maneuverability of vehicle with DFPS system and reduce the negative influence of DFPS system on vehicle stability.

Chuanxue Song, Feng Xiao, Shixin Song, Silun Peng, Jianhua Li, Jilin University, China

Utilizing Energy Analysis Methods to Select Transmission Technologies and Optimize Powertrain-Vehicle System Fuel Consumption

The ideal automatic transmission design harmonizes with the characteristics of the internal combustion engine to transform speed and torque to optimize overall vehicle system performance while minimizing parasitic energy usage for functional operation and refinement. Transmission technologies, operating strategies and shift point selections for optimal acceleration and fuel consumption is multifactorial and best suited for energy methods and statistical based analysis. This presentation focuses on the use of conventional energy methods and statistical techniques to analyze a given vehicle with multiple engines for fuel consumption when combined with various automatic transmission types, launch devices, shift point constraints and levels of parasitic loss. The results are shown as fuel consumption against total transmission energy utilization on a given regulated test schedule. By presenting the results in this manner across the automatic transmission design space for vehicle(s) and engine(s), generalized trends in strategic technology selection and operating strategies can readily be identified to optimize performance. Step gear automatic transmissions are shown to approach a clear asymptote in fuel consumption and energy usage and are less sensitive to parasitic losses. Continuously variable transmissions demonstrate the most potential for fuel consumption benefit by removing the constraints of shift point in a step gear transmission, but is more strongly dependent on the parasitic energy utilization paradigm. Furthermore, the advantages in shift point and incremental parasitic loss reductions are easily explored for a given transmission type versus jumping architectures that may require substantial capital investments.

Darrell Robinette, Daniel Wehrwein, General Motors Co.