Chassis, Control Systems and Equipment

1 Introduction

Automakers are facing ever-increasing demands to reduce the environmental impact of vehicles while also enhancing safety. These demands have prompted rapid measures to electrify powertrains, reduce driving resistance, widen the adoption of electric power steering (EPS), and comply with regulations mandating the installation of electronic stability control (ESC) systems. Other fundamental approaches to address driving performance, including weight reduction by optimizing vehicle structures and adopting substitute materials for steel, are also being proactively carried out. Furthermore, recent years have also seen rapid progress in various active safety and convenience functions through the application of electronic controls to chassis components.

Ongoing measures to enhance environmental friendliness are extremely wide reaching and are not limited simply to the introduction of hybrid vehicles (HEVs) and electric vehicles (EVs). Idling stop systems (ISS) and regeneration controls that actively charge the battery using energy recovered during acceleration are being installed even in conventional engines without drive motors. Functions to boost the voltage of the ESC unit to offset insufficient brake booster vacuum and the development of non-hydraulic EPS have played a major role in achieving in these regeneration and automatic engine stop functions.

Other recent trends include the fusion of omni-directional monitoring functions and vehicle control technology using sensors capable of recognizing the driving environment, such as radar and lasers, which has led to major steps forward in active safety functions. Conventionally, driver support functions have been limited to alerts and warnings. However, higher performance safety systems are now being adopted that actively help to avoid accidents, such as automatic braking and lane departure prevention.

This article describes chassis and vehicle control system technology trends based on new vehicles and technologies launched in 2013 (Table 1).

2 Suspension

2. 1. Base suspensions

As shown in Table 1, front suspensions in vehicles with transversely mounted engines are all strut-type suspensions. Most medium sized and smaller vehicles with longitudinally mounted engines also use strut suspensions. However, larger and sporty vehicles tend to use a double wishbone suspension or a suspension type derived from that configuration. There were no major changes in rear suspensions in 2013, and torsion beam suspensions remain the mainstream type from mini- to compact front-wheel drive (FWD) vehicles. In contrast, De Dion rear suspensions are commonly adopted for all-wheel drive (AWD) versions, and medium sized and larger vehicles tend to adopt double wishbone or multi-link rear suspensions. AWD versions of these vehicles use the same rear suspension types.

In addition, although automakers are continuing to rationalize suspension structures, steady progress is being made in efforts to optimize geometries and compliance characteristics, and to increase stiffness. Since weight reduction is particularly important for HEVs and sporty vehicles, automakers are actively replacing conventional suspension materials with aluminum on these models. One example is the rear suspension of the Nissan Skyline HEV (Fig. 1), which uses aluminum for the main arms. Structures with optimized bushing characteristics (connecting bushings) were also added to another model.

More shock absorbers are using variable damping force mechanisms that change in accordance with the frequency and amplitude of inputs to enhance stability, controllability, and ride comfort, while also improving vibration and noise performance. Conventionally, the most advanced forms of this technology were stroke

Table 1 Chassis and vehicle control systems of new vehicles launched in 2013.

Market	Manufacturer/brand	Model	Category	Drivetrain types (ISS: includes idle stop system)	Drivetrain layouts	Suspension type Front/Rear ( ): suspension for AWD layout	Steering	Vehicle control systems
Japan	Suzuki	Spacia	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/trailing link	EPS	ABS (with EBD and Brake Assist), ESP, Hill Hold Control, Radar Brake Support, gas pedal misoperation control
		Carry	Mini-vehicle	Gasoline	RWD/AWD	Strut/leaf spring	EPS	ABS, EBD
		Hustler	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/trailing link	EPS	ABS (with EBD and Brake Assist), Grip Control, ESP, Hill Hold Control, Hill Descent Control, Radar Brake Support, gas pedal misoperation control
	Subaru	XV Hybrid	SUV	Gasoline HEV	AWD	Strut/double wishbone	EPS	ABS with EBD, Brake Assist, VDC, Hill Start Assist, Pre-Collision Braking, Pre-Collision Brake Assist, Adaptive Cruise Control with all-speed range tracking function, Pre-Collision Throttle Management, Brake Override
	Daihatsu	Mebius	Medium	Gasoline HEV	FWD	Strut/torsion beam	EPS	ABS with EBD, Brake Assist, Steering-assisted Vehicle Stability Control (S-VSC), Hill-start Assist Control
		Tanto	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/torsion beam (3-link)	EPS	ABS (with EBD), TRC, VSC, Smart Assist System (featuring brakes that assist low-speed crash avoidance and gas pedal misoperation control)
	Toyota	Harrier	SUV	HEV	AWD	Strut/double wishbone	EPS	S-VSC, Hill-start Assist Control, Frequency Adaptive Damping, Pre-collision Safety System, Drive-start Control, Lane Departure Alert (with steer assist), Radar Cruise Control
	Nissan	Skyline	Medium	Gasoline HEV	FWD/AWD	Double wishbone/multi-link	EPS	VDC (with Cornering Stability Assist, brake function enhancement function, and lateral braking force distribution function), Brake Assist, Hill Start Assist, Direct Adaptive Steering, Emergency Brake, Active Lane Control, Lane Departure Prevention (LDP), Lane Departure Warning (LDW), Backup Collision Intervention (BCI), Intelligent Cruise Control
		X-Trail	SUV	Gasoline/diesel ISS	FWD/AWD	Strut/multi-link	EPS	ABS+EBD, Brake Assist, VDC, Cornering Stability Assist, Advanced Hill Descent Control, Active Ride Control, Emergency Brake, emergency assist for pedal misapplication, Intelligent Parking Assist
		Serena	Minivan	Gasoline HEV	FWD/AWD	Strut/torsion beam (multi-link)	EPS	ABS, EBD, Brake Assist, VDC, Hill Start Assist, Smooth Start Assist, Emergency Brake, emergency assist for pedal misapplication
		Dayz	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/3-link	EPS	ABS+EBD, Brake Assist, VDC, Hill Start Assist
		NV100 Clipper/Clipper Rio	Mini-vehicle	Gasoline	RWD/AWD	Strut/isolated trailing link	EPS	ABS+EBD
	Honda	Fit	Compact	Gasoline ISS/HEV	FWD/AWD	Strut/torsion beam (De Dion)	EPS	ABS with EBD, VSA (+TCS), Hill-start Assist function, electric-servo brake system, City-Brake Active System (with Collision Mitigation Brakes and False Start Prevention)
		Odyssey/Odyssey Absolute	Minivan	Gasoline ISS	FWD/AWD	Strut/torsion beam (De Dion)	EPS	ABS with EBD, VSA (+TCS), Hill-start Assist, Motion Adaptive EPS, Smart Parking Assist, City-Brake Active System (with Collision Mitigation Brakes and False Start Prevention)
		N-WGN ／ Custom	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/torsion beam (De Dion)	EPS	ABS with EBD, VSA (+TCS), Hill-start Assist, new EPS control
		Vezel	SUV	Gasoline HEV	FWD/AWD	Strut/rigid (De Dion)	EPS	ABS with EBD, VSA (+TCS), Electric Parking Brake, Hill-start Assist, Automatic Brake Hold, City-Brake Active System (with Collision Mitigation Brakes and False Start Prevention)
	Mazda	Axela	Medium	Gasoline HEV	FWD/AWD	Strut/multi-link	EPS	TCS, DSC, Hill Launch Assist, Smart City Brake Support, Radar Cruise Control
		Flair Wagon	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/trailing link	EPS	ABS, EBD, Brake Assist, TCS, DSC, Hill Hold Control, Radar Brake Support, Acceleration Control function
		Scrum Truck	Mini-vehicle	Gasoline	RWD/AWD	Strut/leaf spring	EPS	ABS
		Flair Crossover	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/trailing link	EPS	ABS, EBD, Brake Assist, TCS (Grip Control), DSC, Hill Hold Control, Hill Descent Control, Radar Brake Support, Acceleration Control function
	Mitsubishi	eK Wagon/eK Custom	Mini-vehicle	Gasoline ISS	FWD/AWD	Strut/3-link	EPS	ABS (with EBD), Brake Assist, Hill Start Assist
	Lexus	IS	Medium	Gasoline HEV	RWD/AWD	Double wishbone/multi-link	EPS	ABS (with EBD), Brake Assist, TRC, VSC, Hill-start Assist Control, Electronically Controlled Brake (ECB), VDIM (with active steering), VGRS, Pre-collision Safety System, Radar Cruise Control, Lexus Dynamic Handling (LDH) system, DRS

Table 1 Chassis and vehicle control systems of new vehicles launched in 2013 (cont.).

Market	Manufacturer/ brand	Model	Category	Drivetrain types (ISS: includes idle stop system)	Drivetrain layouts	Suspension type Front/Rear ( ): suspension for AWD layout	Steering	Vehicle control systems
Outside Japan (launched in the home country of each automaker)	Acura	MDX	SUV	Gasoline	FWD/ AWD	Strut/multi-link	EPS	ABS, EBD, BA, VSA, Collision Mitigation Braking System (CMBS)
	Audi	A8 Hybrid	Executive	Gasoline HEV	FWD	5-link/trapezoidal	EPS	ABS with EBD, ASR, ESC, EPB, Hill Hold Assist, Active Air Suspension, Adaptive Cruise Control, Audi Parking System
		Q5 Hybrid	SUV	Gasoline HEV	AWD	5-link/trapezoidal	EPS	ESC, EPB, Hill Hold Assist, Adaptive Cruise Control, Audi Parking System
	BMW	M6 Gran Coupé	Executive	Gasoline ISS	RWD	Double wishbone/multi-link	HPS	ABS, Cornering Brake Control (CBC), Dynamic Brake Control (DBC), DSC, collision avoidance/brake activation, Park Distance Control (PDC), Dynamic Damping Control
		Z4	Medium	Gasoline ISS	RWD	Strut/central arm	EPS	ABS, Cornering Brake Control (CBC), Dynamic Traction Control (DTC), DSC, Dynamic Brake Control (DBC), Park Distance Control (PDC), Adaptive M Suspension
		i3	Compact	EV (with range extender)	AWD	Strut/multi-link	EPS	ABS, Driving Assist Plus (including Active Cruise Control with Stop & Go function, Park Distance Control (PDC)
	Jeep	Cherokee	SUV	Gasoline	FWD/ AWD	Strut/multi-link	EPS	ABS, All-Speed Traction Control, ESC, EPB, Hill Start Assist, Select-Speed Control (Hill-Descent Control, Hill-Ascent Control), Adaptive Cruise Control, Electronic Roll Mitigation (ERM), Park Sense
	Ford	Kuga	SUV	Gasoline	AWD	Strut/multi-link	EPS	ABS with EBD, Emergency Brake Assist, traction control, ESP, Anti-Rollover Mitigation (ARM), Torque Vectoring Control, Hill Start Assist, Active City Stop
		Focus	Compact	Gasoline	FWD	Strut/multi-link	EPS	ABS with EBD, ESP, traction control, Torque Vectoring Control, Hill Start Assist, Active City Stop
	Chevrolet	Corvette	Sporty	Gasoline	RWD	Double wishbone/double wishbone	EPS	ABS, traction control, Active Handling System, Magnetic Ride Control
	Jaguar	F-Type	Sporty	Gasoline	RWD	Double wishbone/double wishbone	HPS	Adaptive Damping, Torque Vectoring
	Land Rover	Range Rover	SUV	Gasoline ISS	AWD	Double wishbone/multi-link	HPS	ABS, EBD, Emergency Brake Assist (EBA), HDC, electronic cross-linked air suspension, ACC with Queue Assist function
	Maserati	Ghibli S/Ghibli S Q4	Sporty	Gasoline/ diesel	RWD/ AWD	Double wishbone/multi-link	Electro-HPS	EPB, Skyhook Suspension
	Mercedes-Benz	S-Class	Executive	Gasoline HEV	RWD	Double wishbone/multi-link	EPS	Brake Assist (BAS) Plus, Magic Body Control, Airmatic suspension, Active Parking Assist, Radar Safety Package (including Pre-Safe brake system, Distronic Plus proximity control system, Active Lane Keeping Assist), Cross-Wind Assist
		C-Class	Medium	Gasoline/ diesel ISS	RWD	Strut/multi-link	EPS	ABS, Brake Assist (BAS) Plus, ESP, Adaptive Brake (with Hold function and Hill Start Assist), Radar Safety Package (including Pre-Safe brake system, Distronic Plus proximity control system, Active Lane Keeping Assist), hydraulic selective damping system
		CLA-Class	Medium	Gasoline ISS	RWD/ AWD	Strut/multi-link	EPS	ABS, BAS, ASR, ESP, Adaptive Brake (with Hold function and Hill Start Assist), automatic emergency braking, Distronic Plus proximity control system, Lane Keeping Assist, Active Parking Assist
	Peugeot	308	Compact	Gasoline/ diesel	FWD	Strut/torsion beam	Electro-HPS	ABS (with EBD), Brake Assist, ESP
		5008	Minivan	Gasoline		Strut/torsion beam	EPS	ESC
	Renault	Captur	SUV	Gasoline	FWD	Strut/torsion beam	HPS	ABS, EBD, ESC (with traction control), Hill Start Assist
	Volkswagen	Golf Variant	Compact	Gasoline/ diesel ISS	FWD/no AWD?	Strut/4-link	EPS	ABS, EBD, Hydraulic Brake Assist, ESP, Auto Hold function (including hill hold assist), Driver Steering Recommendation (DSR), pre-crash braking system, City Emergency Braking, lane keep assist system (multi-collision braking system), Adaptive Cruise Control, DCC Adaptive Chassis Control, Park Distance Control

Fig. 1 Rear suspension of Nissan Skyline HEV.

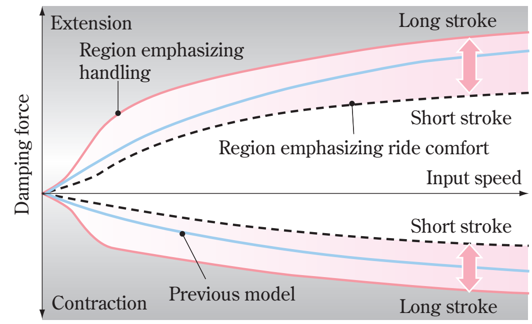

Fig. 2 Amplitude-sensing damper.

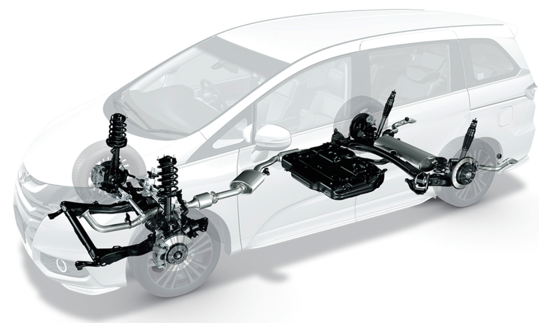

Fig. 3 Chassis of Honda Odyssey.

sensing shock absorbers that were developed to resolve the trade-off relationship between rollover resistance and ride comfort. However, the application of technologies that emphasize both handling and ride comfort has been increasing, such as the frequency adaptive damping (FAD) shock absorbers on the Toyota Harrier, the double piston shock absorbers on the Skyline, and the selective damping system on the Mercedes-Benz C-Class.

A specific example is the amplitude-sensing dampers used on the Honda Odyssey. These reduce the damping force in high piston speed, low-stroke operating regions to enhance ride comfort without sacrificing stability and controllability (Fig. 2). The same model also features a specially designed thin chassis that ensures both handling performance and ride comfort while expanding the height of the cabin. This chassis design incorporates the fuel tank to achieve a low floor and center of gravity (Fig. 3).

2. 2. Suspension controls

A wide variety of suspension controls have been put into practical use, including air suspensions, active suspensions, stabilizer controls, and variable roll stiffness functions connected with the stroke of each wheel. However, the adoption of electronically controlled shock absorbers is becoming more widespread, mainly in vehicles from European automakers. A growing number of vehicles include systems that allow the driver to switch between modes that change the characteristics of the whole vehicle in accordance with the desired driving style. These systems feature damping force mode switches on the steering wheel and operate by connecting and integrating the suspension with electronic power unit controls.

Although there were no major changes to the basic variable damping force mechanisms in 2013, system performance enhancements were pursued by the addition of various preview-type functions. These included the NAVI AI-Adaptive Variable Suspension (AVS) system on the Lexus IS that combines vehicle location information with navigation system map data, and the Magic Body Control system of the S-Class, which detects uneven road surfaces in advance using forward cameras (Fig. 4). Some systems also used existing ultrasonic sensor technology for dedicated suspension controls to measure the distance to the road surface. However, as information communication devices and driving environment recognition technologies become more widespread, rational and higher performance vehicle controls that share sensor signals between control systems are likely to become more common.

3 Steering

The adoption of EPS is a common approach to improve fuel efficiency. The steering characteristics of EPS have improved rapidly from the dual standpoints of improved structures and electronic controls. As a result, EPS systems are now finding a foothold even in sporty vehicles that emphasize steering feel. There were no major changes to EPS systems in 2013 and the column-assist type of EPS remains the mainstream in compact

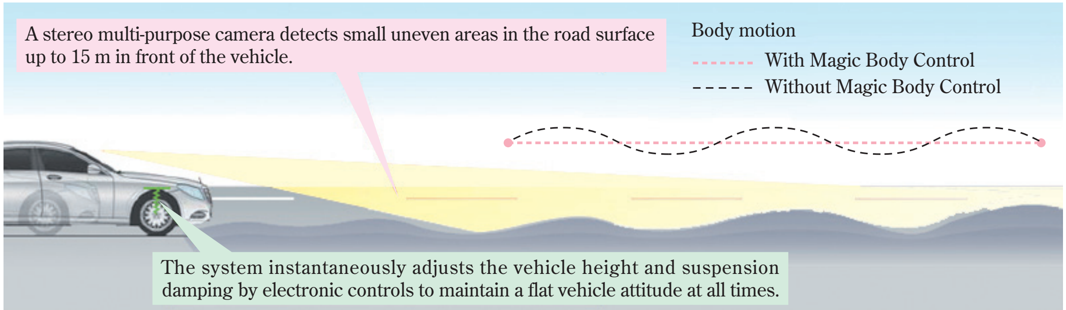

Fig. 4 Magic Body Control system.

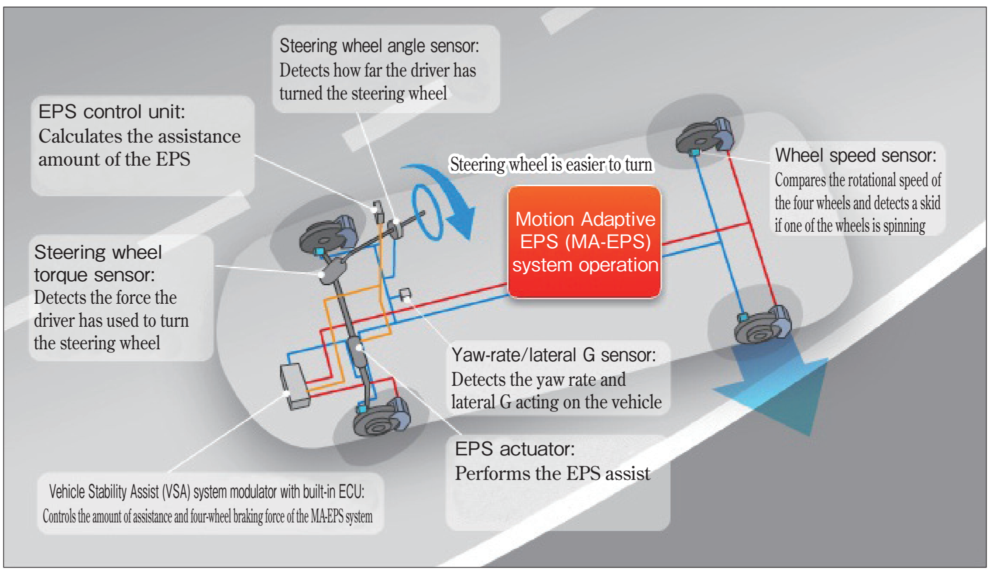

Fig. 6 Motion Adaptive EPS system.

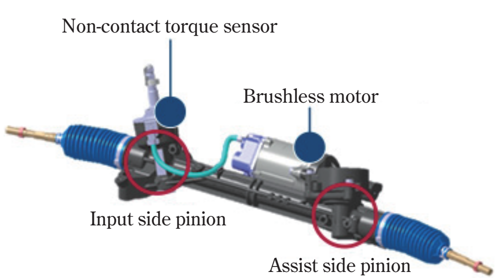

Fig. 5 Dual pinion type EPS.

class and smaller vehicles. Although rack-assist EPS systems are most common in medium-sized and larger vehicles due to the power requirements of the system, more vehicles are adopting a dual pinion type EPS (Fig. 5) to further increase power. Electronically controlled steering support functions have also rapidly become more functional and widely adopted. Examples include lane-keeping functions and lane departure prevention controls, as well as sophisticated parking support functions that also incorporate brake controls. In the future, systems that cooperate with ESC to support steering corrections when the vehicle begins to skid are likely to become even more widespread. One example of this is the Motion Adaptive EPS system on the Odyssey (Fig. 6).

Steering wheel torque sensors are a critical element of EPS systems. Steering wheel torque is a vitally important piece of information for identifying driver intention from the standpoint of the functional requirements of active safety. In combination with steering wheel angle signals, each control system in the vehicle uses this information received via the on-board local area network (LAN).

Examples of even more proactive functions already in practical use include active steering systems that electronically control the steering angle and steering gear ratio with respect to the steering wheel angle. The Direct Adaptive Steering system in the Skyline HV (Fig. 7) is the first example of a steer-by-wire system on the mar-

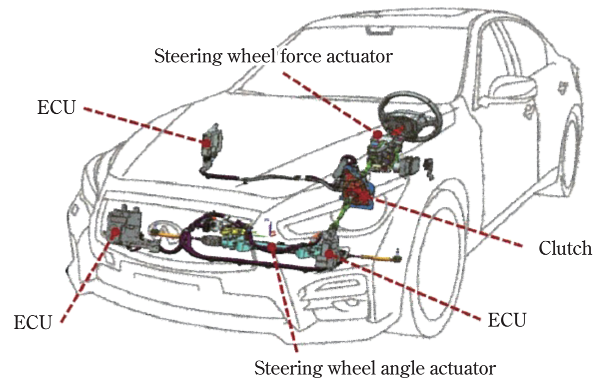

Fig. 7 Direct Adaptive Steering system.

ket. This system has no mechanical connection between the steering wheel and the front wheels, and can apply the necessary steering wheel torque freely. It also features a control that compensates for steering kickback caused by ruts to make it easier for the driver to steer the vehicle. As a by-wire system has extremely stringent safety and reliability requirements, three control units and two steering actuators are provided to create a multiplex fault-response system. In addition, if the system loses power, a backup clutch will engage to connect the steering wheel and wheels directly.

4 Brakes

The installation rate of ESC systems has risen in the period approaching the date of mandatory adoption. In accordance with this trend, controls to hold vehicles stationary on gradients using the pressure boosting functions of ECS have become standard equipment on many vehicles. In addition, the number of SUVs installed with hill descent systems that control vehicle deceleration when driving downhill has increased. The operating regions of ESC have also been expanded, resulting in the development of more vectoring systems that improve cornering performance by applying braking force to the inside wheels of a turn.

As mentioned above, ESC-based electronic controls are a fundamental piece of technology for maximizing energy regeneration in HEVs and holding vehicles equipped with ISS stationary. Furthermore, in addition to more proactive collision avoidance systems that use automatic braking, the application of ESC systems is being widened to include lane departure prevention controls that use the brakes to apply yaw moment. Another example is the electric parking brake (EPB), which has conventionally been regarded as a system to improve user convenience. The EPB can also function to hold the vehicle completely stationary after automatic braking.

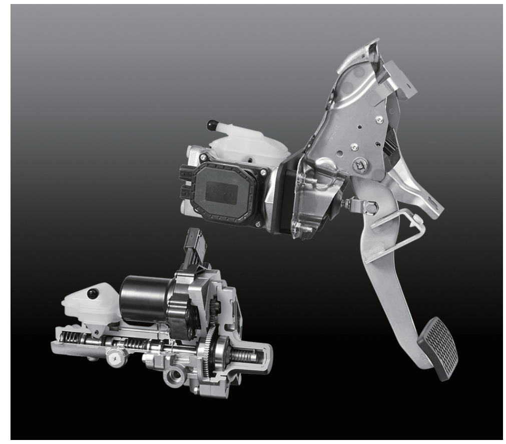

Fig. 8 Electric-servo brake system.

In contrast, electric boosters that combine a driver-operated booster system with an automatic pressure boosting function may be considered as a possible solution to eliminate brake operation interference by the driver and to improve pedal feel for automatic brakes as well as regenerative brakes. One leading example of this is the electric-servo brake system in the Honda Fit (Fig. 8).

5 Other Vehicle Controls

Controls to limit changes in the sprung attitude of the vehicle are becoming more prevalent in SUVs. These controls make active use of the pitching moment of the brakes and driving force, or the vertical force components (anti-dive and squat) of the suspension links. The Active Ride Control system of the Nissan X-Trail (Fig. 9) controls the engine and the brakes, and a similar system in the Harrier HV controls the drive motor, thereby limiting unnecessary pitching on poor roads.

The preceding sections have highlighted the extremely close mutual relationship between vehicle electrification and the adoption of electronic chassis controls. In fact, the introduction of electrified powertrains has also stimulated some fundamental revisions to basic chassis structures. A major issue for EVs is the need to install a large-capacity battery to extend cruising range. The LifeDrive architecture used on the BMW i3 creates separate chassis and cabin modules to expand the battery installation space (Fig. 10). The lower model is a 100% aluminum chassis developed especially for EVs. In addition to reduced weight, it was also designed from the standpoint of collision safety and to lower the center of

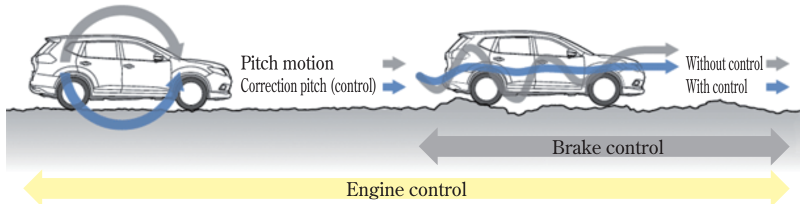

Fig. 9 Active Ride Control system.

Fig. 10 BMW i3 LifeDrive chassis architecture.

gravity of the vehicle by installing the batteries under the floor.

In realizing controls that successfully integrate the high levels of chassis and safety performance expected of vehicles in the future, the required reliability levels of control system power sources as detailed by ISO 26262 are extremely stringent. Even from the standpoint of the actuator technology that will stand behind the future development of autonomous driving systems, power supply and management systems for chassis control systems are likely to become a critical piece of basic technology.