Chassis Control Systems for Safety, Environmental Performance, and Driving Comfort

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OVERVIEW: Chassis subsystems, such as suspensions, steering, and brakes, play an important role in determining driving, cornering, and stopping performance of a vehicle. Hitachi supplies a wide range of such products and has drawn on technologies, which have built up with conventional products to incorporate electronics and electric drive into these systems. By drawing on capabilities from throughout Hitachi, including making further enhancements to cooperative control techniques for electric powertrains of HEVs and EVs and for engine-driven powertrains (a field in which progress is being made on improving fuel economy), integrating information and recognition systems such as car navigation and cameras, and developing systems for integrated control of chassis subsystems and for autonomous driving, Hitachi is seeking to be a supplier that can provide the entire world with vehicles that are safer, greener, and more comfortable.

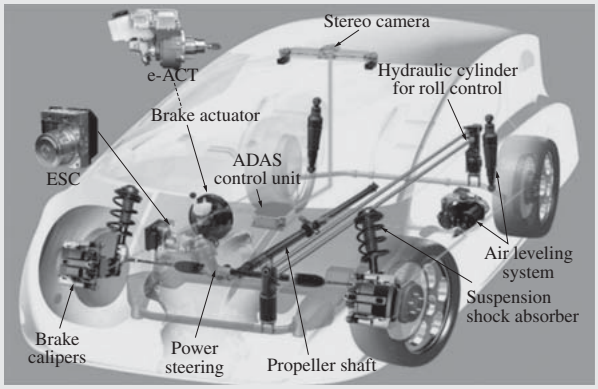
INTRODUCTION

ELIMINATING traffic accidents is an ever-present objective for society, and factors such as aging drivers are behind stronger demand for accident prevention systems. Along with electronic stability control (ESC) for preventing skidding, there are also moves toward mandating systems that brake automatically in emergent situations.

Meanwhile, hybrid electric vehicles (HEVs) and electric vehicles (EVs) are entering wider use in response to growing environmental awareness prompted by global warming. These electrically powered vehicles require systems that cooperatively control friction and regenerative braking (braking using electric motor), and also electric drives for subsystems such as power steering and braking to avoid relying on drive force or vacuum provided by engine. Progress is also being made on innovative techniques for improving fuel economy of engine-powered vehicles, with growing demand for systems that can turn off engine not just during idling, but also prior to stopping or when coasting.

Semi-active and active suspensions not only enhance ride comfort and improve handling, they also help make evasive action more effective and reassure passengers by maintaining stability when trying to avoid an accident.

Development continues on further improvements to safety, achieved by utilizing information such as map data from car navigation systems, recognition data from cameras and radar, and information acquired via car-to-car communications and car-to-infrastructure communications, with growing activity in the development of technology that has potential for use in autonomous driving systems. Through integrated control involving the cooperative interoperation of these technologies with chassis control systems, Hitachi is picking up the pace of development for systems that further enhance safety, environmental performance, and driving comfort of vehicles (see Fig. 1 and Fig. 2).



ESC: electronic stability control e-ACT: electrically-assisted actuation
ADAS: advanced driver assistance system

Fig. 1—Chassis Control System Products.
Hitachi supplies a variety of products for chassis systems, which play an important role in determining the driving, cornering, and stopping performance of a vehicle.

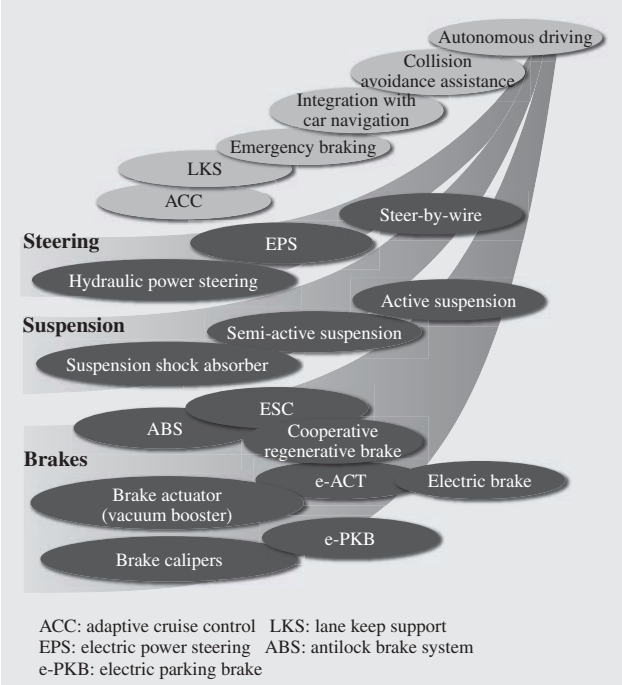


Fig. 2—Advances in Chassis Control Systems.
By drawing on technologies it has developed with conventional products to incorporate electronics and electric drive and enhance cooperative control techniques, Hitachi is creating vehicles that are safer, have better environmental performance, and are more comfortable.

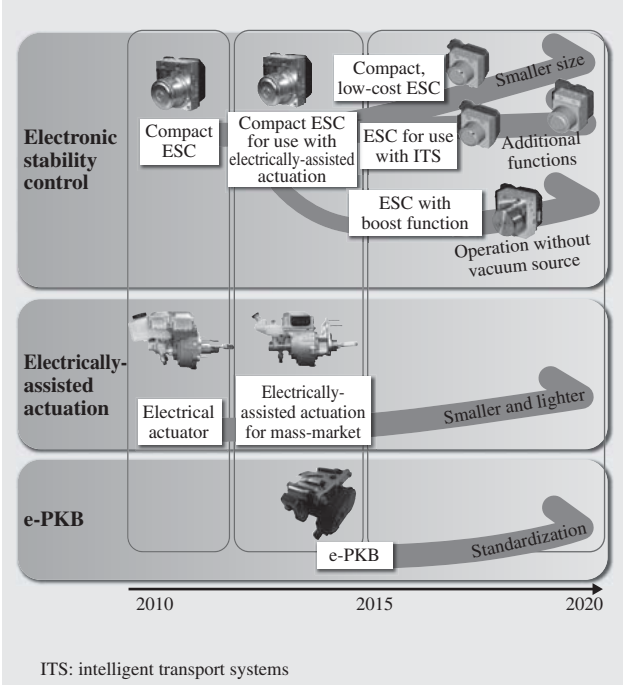


Fig. 3—Roadmap for Controlled Brakes.
With a product range that includes skidding prevention systems, electric actuator, and e-PKBs, Hitachi supplies brake systems that cover everything from normal driving conditions to extreme cases.

This article describes the current state of development of chassis control systems and the outlook for the future.

BRAKE SYSTEM

Developments in Brake Technology

Brake systems can be broadly divided into the "service brake" that decelerates a moving vehicle when the driver applies the brake pedal and the "parking brake" that prevents a stationary vehicle from moving. In addition to braking and parking, brake systems are also being required to provide greater safety, with antilock brake systems (ABSs) that prevent wheel lock and ESC that prevent vehicle spin and drift-out that becoming standard features. The safety, comfort, and environmental performance of vehicles have also been improved through optimal control of the braking force, with greater use being made of electric drive in parking brake mechanisms and devices for boosting the braking force applied by the driver. Controlled brakes have become critical parts when considering the performance of modern vehicles. Against the background of these trends, Hitachi is developing ESC, electrically-assisted actuation, and electric parking brakes (see Fig. 3).

ESC

ESC systems use sensors to monitor for behavior of vehicle instability (tire lock, wheel spin, vehicle spin, and drift-out), and control the braking force at each wheel to stabilize the vehicle. Hitachi has been commercializing the pressure sensor-less compact ESC systems since 2003. Next generation compact ESC system was released in 2007 with additional functions that included active rollover protection control and hill start assist control. The growing demand for ESC system is to reduce the size and weight and extend functionality, Hitachi is currently developing a low-cost ESC system that is 20% smaller and lighter than the current model. That target is emerging markets and small vehicles.

Meanwhile, the function controls the brake force to stabilize the vehicle behavior and the function of autonomous brake cooperates with camera, radar and/or other sensors operate not only the emergency condition but normal driving condition. Because of the need, ESC should be quieter, more responsive, and more durable, Hitachi is developing a system that utilizes its own gear pump technology.

As small vehicles, HEVs, EVs, and fuel-efficient green vehicles are being more widely adopted, and so there is growing demand for brake boost mechanisms

that do not rely on vacuum from the engine. Hitachi is currently developing a compact ESC system for small vehicles that includes the boost function. Because the overall brake system has been made smaller and lighter through the integration of functions, making it easier to fit inside a vehicle, Hitachi anticipates that the new system will be widely adopted.

e-ACT

As an alternative brake actuation, Hitachi has been the first in the world to develop and commercialize its own electric brake actuator that uses a servo mechanism that does not rely on vacuum from the engine. Instead an electric motor assists the pedal force provided when the driver operates the brake pedal.

This electrically assisted actuation (e-ACT) includes a function for working in cooperation with the regenerative brake on an HEV or EV (see Fig. 4). It helps improve fuel economy by utilizing the superior control performance provided by an electric motor to obtain the optimal level of braking force from the friction brake, thereby significantly increasing energy regeneration by the regenerative brake. It also enhances vehicle safety and driving comfort by utilizing the precise control performance of e-ACT to implement automatic braking and other intelligent transport system (ITS) functions in conjunction with sensors such as cameras or radar. With an ability to modify the pedal feel by software, the system also provides added value not available on conventional brake system.

The popularization of HEVs, EVs, and ITS functions is driving growing demand for brake actuator with a high level of controllability. To improve fuel economy, safety, and driving comfort, Hitachi is developing and promoting low-cost e-ACT products that feature small size, light weight, and ease of installation to allow this technology to be utilized by a larger number of vehicle models in the future.

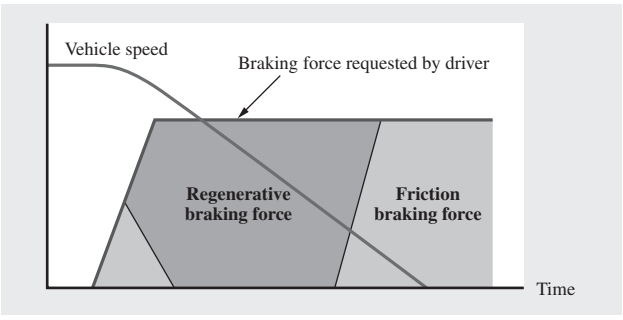


Fig. 4—Cooperative Control of e-ACT and Regenerative Brake. e-ACT works in conjunction with the regenerative brake, adjusting the friction brake and controlling the two mechanisms in tandem to provide the driver with the intended braking force.

e-PKB

There is an ongoing trend toward the use of electric parking brakes (e-PKBs) with the aim of providing simpler operation and greater flexibility in interior layout. To make automatic parking brakes possible, Hitachi has minimized brake noise, increased the speed with which the parking brake can be released, and adopted its own actuators, which combine transmission efficiency with an ability to maintain clamping force. Through these initiatives, Hitachi is considering safety and the environment by reducing the weight of the overall brake system, making the calipers and motor smaller and lighter, and also ensuring that the system works with idling stop systems and collision prevention and minimization systems.

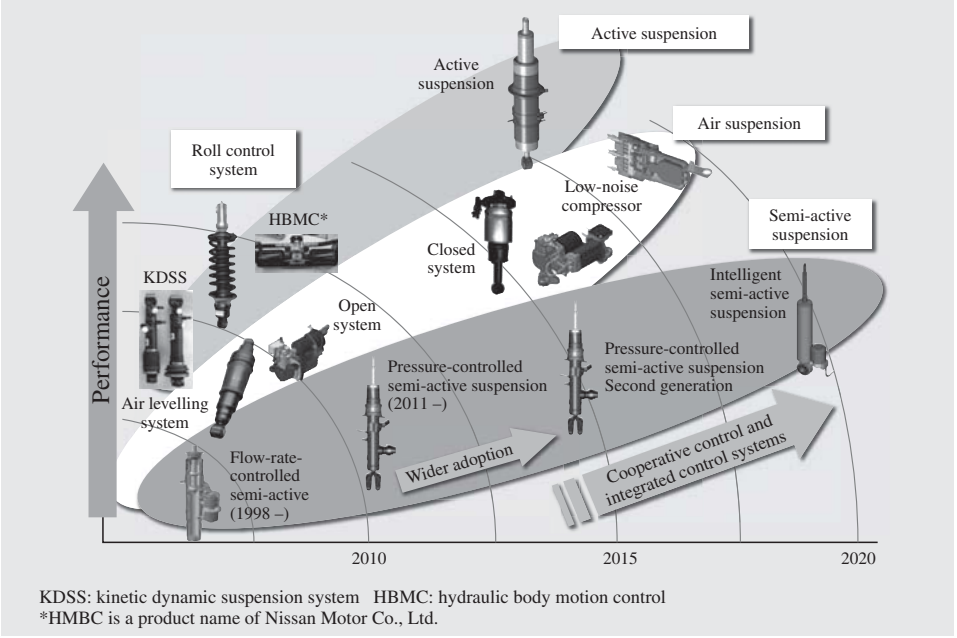
SUSPENSION SYSTEMS

Developments in Suspension Technology

Through its influence on ride comfort and handling, the suspension is an important system for ensuring driving comfort by providing a sense of stability and reassurance and by being less tiring for the driver. In particular, controlled suspensions provide a high level of both handling and ride comfort. At the same time that greater use is being made of these in small, low-cost vehicles, mainly in the form of semi-active suspension, progress also continues on improving performance through integrated control and cooperative operation with other chassis control systems (see Fig. 5).

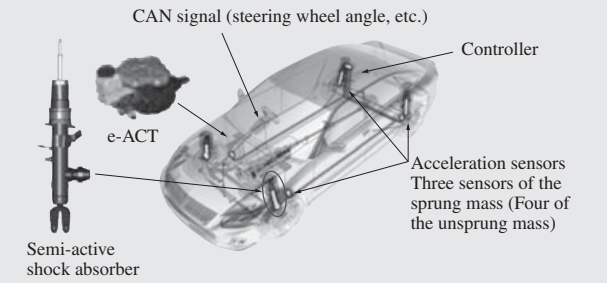
Semi-active Suspension

Semi-active suspension controls the damping force characteristics of shock absorbers on the basis of vehicle body movement to reduce vibration in the 2 Hz–8 Hz range, to which people are most sensitive (becoming nauseated), while also suppressing other low-frequency shaking of the vehicle body. Hitachi has used its own control valve designs to develop shock absorbers for semi-active suspension that provide a wide range of damping forces and quick response. These shock absorbers have been adopted in an increasing number of vehicles, primarily high-end models. In addition to reducing the size and cost of the shock absorbers so that they will be used more widely, Hitachi's plans for the future include developing cooperative control systems that work with controlled



KDSS: kinetic dynamic suspension system HBMC: hydraulic body motion control
*HMBC is a product name of Nissan Motor Co., Ltd.

Fig. 5—Roadmap for Controlled Suspension.
Use of semi-active suspension, in particular, is extending beyond top-end models to also include small, low-cost vehicles, with performance improvements being achieved through integrated control in cooperation with other chassis control systems.

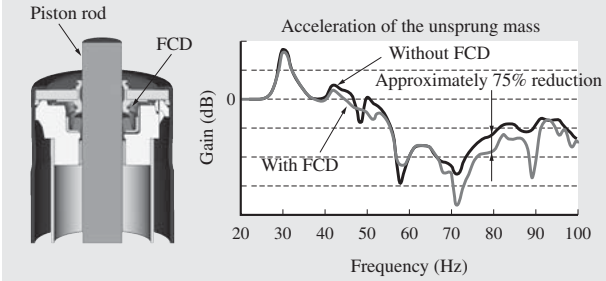


Example semi-active suspension system
[Cooperate with electrically-assisted actuation (e-ACT)]

(a) From vehicle testing **(b) From kinematic analysis of vehicle (CarSim*)**

CAN: controller area network
* CarSim is a trademark or registered trademark of Mechanical Simulation Corporation of the USA.

Fig. 6—Cooperative Control System for Semi-active Suspension and Controlled Brake.
Cooperative control of the semi-active suspension and brake (e-ACT) can improve vehicle stability when taking evasive action.



FCD: friction control device

Fig. 7—Structure and Benefits of FCDs.
Fitting FCDs significantly reduces high-frequency vibrations of the unsprung mass with major benefits for ride comfort.

brakes and other subsystems with the aims of making evasive action to prevent an accident more effective and providing reassurance (see Fig. 6).

Improvements to Ride Comfort

This section describes friction control devices (FCDs), a technology for improving ride comfort. FCDs are useful for reducing vibrations in the high-frequency range (30 Hz and higher), which are difficult to control through hydraulic damping force and yet are an important aspect of improving ride comfort. FCDs help achieve better ride comfort, with specific benefits that include smooth standing starts, reducing the shock of driving over bumps, and less tire pattern noise. Their uses in recent years have included light vehicles, where they provide a means of preventing the harsh ride that results when using a set of fuel-efficient tires whose inflation pressure is tipically higher than normal tires, and run-flat tires to improve ride comfort and reduce pattern noise while still improving safety. Hitachi has already been producing FCDs for more than a decade, during which time they have entered wider use, and has developed improved versions to satisfy the rising level of expectation for ride comfort (see Fig. 7).

Along with advances in electronically controlled suspension, improving on technologies like this one is an important challenge, and Hitachi is working on products that match customer needs by further developing and combining both electronically controlled systems and mechanical techniques.

STEERING SYSTEMS

Developments in Steering Technology

Use of electric power steering (EPS) has grown steadily since it was first adopted in light vehicles in the late 1980s, with a forecast that approximately 50% of all vehicles manufactured in 2015 will have EPS. This is a consequence of how the high price of oil and growing environmental awareness in recent years have focused attention on fuel economy, and also, EPS provides estimated fuel savings of approximately 3% to 4% is the reason. In Japan, where the number of models available as HEVs or with idling stop is growing, it is estimated that approximately 80% of 2015 vehicles will use EPS. Given these circumstances, Hitachi has focused its product range on pinion EPS (PEPS), and is also developing dual-pinion EPS (DEPS) and belt-drive EPS (BEPS) for higher output and better steering feel (see Fig. 8).

EPS with Better Steering Feel

With an increasing number of vehicles including EPS as standard equipment in recent years being in their second or third generation, there are growing demands for EPS to provide better steering performance and to minimize minor steering uncomfortable behavior transmitted from the vehicle. Hitachi has developed the logics for achieving this. Fig. 9 shows effectiveness of the disturbances suppressing control. By using control logic of minimizing the steering wheel vibration caused by juddering or kickback from the road surface, the steering wheel vibration was reduced about 30%. Also, Fig. 10 shows an example of applying the control logic of friction compensate in the EPS's mechanical systems, where almost 66% of the steering wheel torque in starting to turn was reduced. This gives drivers an easier steering feel, requiring less effort to make small steering angle adjustments. The control logic can also be modified for use with active steering based on steering inputs from other systems and corrections for assist curve characteristics, and the interfaces and software structure having a system configuration that can handle diversified requirements.

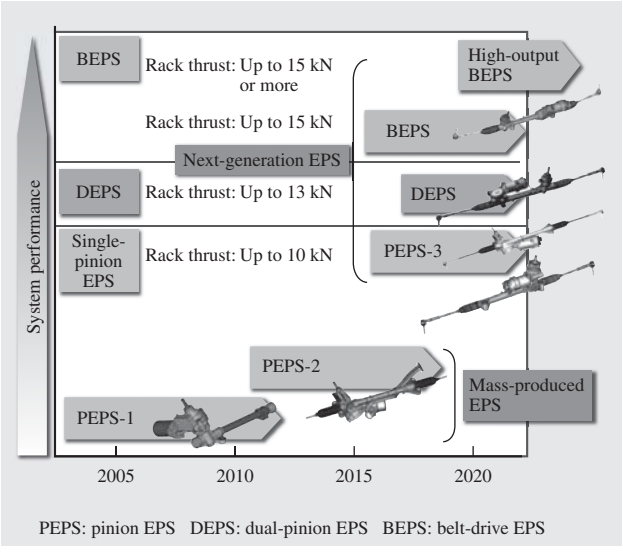


Fig. 8—Roadmap for EPS.
In addition to PEPS, Hitachi is also developing DEPS and BEPS to suit a wider range of vehicles.

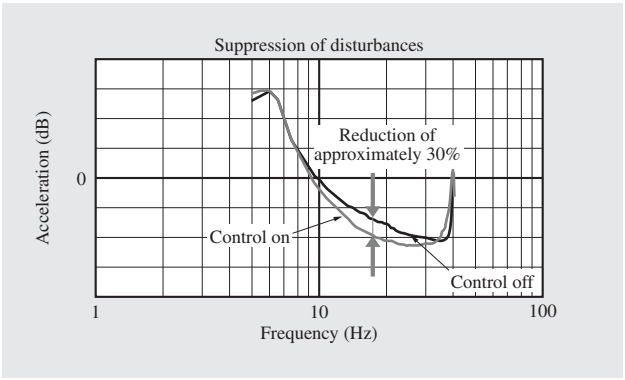


Fig. 9—Effectiveness of Control Technique for Suppressing Disturbances.
The control technique improves the feel of steering by reducing the transmission to the steering wheel of kickback from the road surface and of unpleasant vibrations.

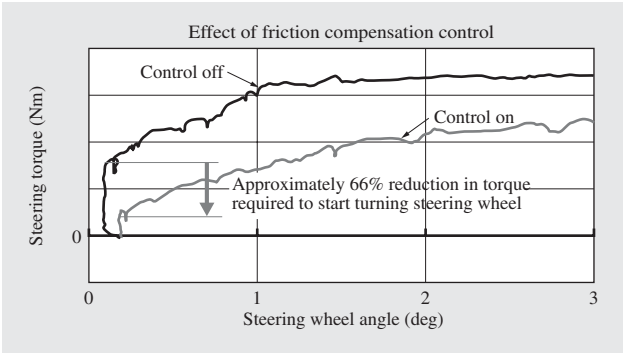


Fig. 10—Effectiveness of Friction Compensation Control.
A control system that compensates for friction in mechanical systems provides a smoother feel to the steering by significantly reducing the torque required to start turning the steering wheel from the center position.

Functional Safety

The ISO 26262 international standard for functional safety was published in 2012 and Original Equipment Manufacturers (OEMs) and suppliers globally introduce to this safety concept into products development. As the global consensus is that the automotive safety integrity level (ASIL) that applies to EPS is level D, the top level of safety design is required. To achieve the requirement, redundancies are adopted for crucial sensors and dual-core and lock-step configurations are used in microcomputers. There has also been growing demand recently for a "keep assist" feature that keeps the steering assist function working in the event of a breakdown. Hitachi intends to develop systems in the future that will satisfy even higher safety requirements.

CONCLUSIONS

This article has looked at brakes, suspensions, and steering, describing the current state of development for chassis control systems and the outlook for the future.

Chassis control systems include many safety-critical components, with each subsystem requiring high reliability. A high level of functional safety performance is also essential if these are to be controlled in an integrated way through interoperation with other systems. Advances in integrated chassis control systems can provide vehicles with a high level of safety, environmental performance, and driving comfort.

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