Vehicle Dynamics

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1 Introduction

Despite the shrinking population and other negative business trends, the Japanese economy is showing signs of an export-led recovery as financial easing by the government helps to reduce the value of the yen.

Imported vehicles (7%) and mini-vehicles (36%) make up 43% of the Japanese vehicle market. Automakers are therefore faced with the urgent task of boosting the appeal of full-sized vehicles manufactured in Japan. In Asia and other markets outside Japan, positive consumer sentiment is leading to robust sales. However, even with favorable exchange rates for exports from Japan, Japanese automakers are finding it difficult to secure profit margins as it becomes necessary to shift production to these strong markets under the principle of local production for local consumption.

In the field of vehicle dynamics, the introduction of regulations mandating the installation of active safety devices to prevent accidents is leading to advances in absolute performance levels and uniformity. The addition of subjective performance aspects such as price and fuel efficiency has created a three-way approach to differentiation, leading automakers to launch an extremely wide variety of products on the market.

Aided by the wider availability of aluminum, conventionally an expensive material for vehicles, has allowed automakers in Europe and the U.S. to make progress in reducing vehicle weight by substituting other materials for aluminum. Japanese automakers have found it harder to balance cost and weight requirements related to the use of aluminum and have yet to determine a coherent strategy.

Japan is a resource-poor country with little available aluminum and energy sources. Weight reduction of the body and suspension, which affects driving performance and fuel efficiency, can only be made more efficient through the quality of basic structures. Therefore, technological competition in this direction is likely to grow. Japanese automakers are in possession of such technology, which may lead to greater business opportunities in the future.

2 Tires

The spread of fuel-efficient tires as a measure for helping to preserve the global environment has maintained the strong focus on research themes related to tire rolling resistance. As research into rolling resistance advances, proposals for developing better balanced and higher performance tires are being made. These trends include research into the required conditions for ensuring the validity of tests under different ambient temperatures to measure running resistance more accurately [(1)], methods to calculate the effects of tread temperature during driving on tire characteristics (such as rolling resistance coefficient (RRC) and cornering performance) and to estimate tire performance from tire temperature, how to consider internal tire pressure to achieve both running resistance and cornering performance [(2)], tire structural improvements focusing on global dynamic slip behavior of the tire contact surface, development of technology for measuring and visualizing localized ground-contact behavior of the tread pattern [(3)], examinations of the running resistance generation mechanism of standalone tires to identify the relationship between the tire usage state and running resistance while cornering [(4)], research to reduce tire vibration by identifying the dynamic vibration characteristics of tires when in contact with the ground and not rotating from the contribution ratio of tire vibration with respect to increased sensitivity and noise in the occupant compartment based on the vibration of the tires themselves as tire weight reduction advances [(5)].

Research is also likely to continue into ways to achieve a strong balance between rolling resistance and other performance aspects in accordance with the greater adoption of replacement tire labeling systems. Related to fuel efficiency, reports have been published describing the development of evaluation methods to identify tire losses in vehicle test cycle driving more easily, as well as methods that use this information to predict the effects on fuel efficiency [6][7]. Although not directly related to vehicle dynamics, one means of extending the cruising range of electric vehicles is to transmit high-frequency electricity from the road surface using the tires as conductors [8].

3 Braking and Driving Characteristics

Electronic stability control (ESC) is an effective means of helping to prevent vehicles spinning or leaving the road when cornering. Growing safety awareness has led to ESC become standard or optional equipment on more vehicles, including mini-vehicles. Advances are being made to reduce cost and weight, improve quietness, and develop additional functions.

To extend the merits of ESC from correcting vehicle limit behavior to normal cornering, research has been published about the G-vectoring concept, which aims to control deceleration in coordination with lateral motion [9].

One automaker has developed the Vehicle Dynamics Integrated Management (VDIM) concept that enhances safety by combining steering controls for the front and rear wheels [10]. The adoption of ESC is also spreading in commercial as well as passenger vehicles. Consequently, research and development has been published describing the estimation and stabilization of load fluctuations particular to commercial vehicles [11].

More electric and hybrid vehicles are being launched onto the market. Trends in this field include development to enhance handling by driving force control using highly responsive motors in addition to energy recovery by regenerative brake systems [12], research into traction control methods suitable for the road surface using in-wheel motors (IWM) [13], and research into tire force distribution optimization control to reduce energy consumed by friction between the road surface and tires [14].

Research is likely to continue into ways of enhancing safety, performance, and fuel efficiency by optimizing braking and driving characteristics.

4 Directional Stability

The adoption of electric power steering system (EPS) continues to increase as a means of improving fuel efficiency. Steer-by-wire (SBW) and four-wheel steering (4WS) systems are also being actively researched and developed. Typical reports have described the effects of steering reaction torque of SBW systems on the ease of vehicle control [15], and the development of a front and rear wheel steering system that enhances both driver comfort and vehicle stability [16]. Research into integrated control systems integrating direct yaw moment control (DYC) and the like is also making progress.

Although advances in these control systems has greatly increased the degree of freedom (DOF) for designing directional stability, one issue is the definition of target values from the standpoint of optimum characteristics for the driver. Driving simulators (DS) have been used in several cases of research to shed light on this issue.

Typical cases of research using DS equipped with front and rear wheel steering systems include a study of target vehicle motion in low-speed cornering [17], a description of the relationship between driver peace of mind and vehicle body slip angle characteristics in high-speed cornering [18], and an evaluation into basic vehicle response parameters and steering characteristics [19].

There has also been a gradual re-appreciation of the importance of basic theory. This trend includes reports describing the relational expressions for yaw rate and side slip angle in vehicle stability and controllability [20], and the effects of steering torque characteristics on the human-vehicle system [21].

In the future, such cooperation between advanced control system development and basic research may well lead to systems capable of achieving even higher levels of stability and controllability.

5 The Human-Vehicle-Environment System

Although the automobile is a means of transporting people and goods, it differs from other means of transportation in that it is operated by the driver through the steering wheel and other systems based on the response of the vehicle to driver inputs as well as information obtained by the driver from the vehicle due to external inputs.

Consequently, steering feel (i.e., the response of the vehicle with respect to the expectations of the driver) remains at the center of continued research into objective evaluation and improvement methods [22].

Many instances of research have been reported in recent years related to human characteristics when driving. One example is a quantitative study to facilitate driver steering operations by analyzing physical behavior using motion capture technology [23].

Other research is aiming to help prevent rear-end collisions, one of the most common type of traffic accidents. This research is examining technology for recognizing driver states such as drowsiness and the like, and for providing warnings.

Examples of studies into practical driver state recognition technology and warnings for unsafe situations include methods of measuring lateral displacement from vehicle behavior [24] and fluctuations in vehicle speed and vehicle-to-vehicle distance [25], as well as methods that use steering wheel operation characteristics based on fluctuations in input from the driver to the vehicle [26][27]. Other examples of methods to directly observe the driver include the provision of sensors on the seat to detect respiratory [28] or heart rate waveforms [29], and state detection methods that use a camera to identify changes in facial expression [30].

Other trends related to the vehicle-driver environment include the diversification of driver characteristics as typified by the growth in the number of elderly drivers. As measures to respond to this trend become more important, basic research is increasingly focusing on analyzing the characteristics of elderly drivers. This research has reported that elderly drivers are self-aware about the deterioration in physical capabilities for safe driving, and are implementing risk avoidance measures such as reducing driving on busy main roads [31][32].

Future research is aiming to develop safer and more comfortable vehicles. This includes research into vehicles that meet the requirements of drivers as active vehicle operators, driver state recognition to help prevent accidents due to human error, and the diversification of driver characteristics such as the increasing proportion of elderly drivers.

6 Limit Performance

At the limits of vehicle dynamics, research is continuing from the standpoint of helping to prevent accidents. This includes the development of technology to enhance basic vehicle performance and to avoid accidents using controls.

One reason for this trend is the obligation to install skid-prevention devices (i.e., ESC) on newly registered passenger vehicles from 2012, and to clear various legal requirements.

For this reason, research has also started to shift to the adoption of ESC on commercial vehicles, something that is scheduled to become mandatory in the future, simulations to minimize actual vehicle tests for regulation and certification, and the definition of evaluation methods for active safety technology.

Since the weight and center of gravity of commercial vehicles fluctuate greatly depending on the load, the adjustment of control parameters is a key issue. One report has described a method of estimating weight fluctuations caused by changes in the laden state using driving force and longitudinal acceleration [33]. In the field of simulation technology, an example of a step-by-step study consisting of hardware in the loop simulation (HILS) for braking controls performed before a full simulation model has been reported [34]. Automakers are also working on popularizing safer vehicles and accelerating the development of safety technology by accurately evaluating and releasing performance information about vehicles equipped with ESC.

Research is also continuing to examine stability in the roll direction as well as planar motion used by ESC. One report described the results of a study using a 15-DOF model to analyze the effects of roll axis height on anti-rollover performance [35]. Another studied vehicle dynamics using a 3-DOF model that integrated roll into a planar 2-DOF model and reported the existence of stability limits that lead to vibrationally unstable states when roll steer becomes under steer (US) [36].

In addition to this basic research, other reports have described the development of a device that detects laden states such as overloading and extremely uneven loading to help prevent the rollover of trailers since such rollover accidents often result in serious injuries [37], and the development of a system that warns the driver when a potential rollover speed has been reached based on center of gravity information obtained using three-dimensional center of gravity detection theory in addition to detecting the center of gravity position [38].

As described above, ongoing research, which includes technology to ensure active safety by enhancing limit performance as well as studies and control technology for basic vehicle characteristics, should help to achieve an even safer vehicle-based society in the future.

7 Intelligent Controls

This section summarizes active safety systems and driver support systems as examples of intelligent controls.

The key issue for active safety systems is the popularization of the collision avoidance systems known as pre-crash safety or pre-collision systems. Europe is planning to introduce ESC into the European New Car Assessment Program (Euro NCAP) for all new vehicles in 2014. Japan is also studying measures for the Japanese New Car Assessment Program (JNCAP) from 2014. As a result there are major expectations for the popularization of this technology and market expansion.

Consequently, there is growing interest in pre-collision systems, as well as research into evaluating system performance and estimating system effectiveness. Reports have described concepts of pre-collision system performance, proposed evaluation and test methods, and estimated the effects of systems in reducing pedestrian fatalities and injuries [39][40]. Another report analyzed low-speed rear-end collisions in Japan using a near-miss database and used these results to study methods for evaluating pre-collision systems [41]. Four indices to evaluate the appropriateness of safe driving focusing on warning functions have been proposed [42] and other research has examined pre-collision systems compatible with pedestrians. This research includes proposed pedestrian detection methods using monocular cameras. Since approximately 60% of accidents involving pedestrians occur at intersections, one proposed system structure uses a monocular camera to ensure a wide detection range [43].

Another proposed system design was created from the standpoint of building a risk-avoidance driver model involving pedestrians [44].

Many pre-collision systems activate automatic braking when a rear-end collision with the vehicle ahead becomes inevitable. To help reduce the risk of a rear-end collision, a brake assist system has been proposed that integrates the potential energy of a spring-mass system in the design [45].

Examples of research into fields outside pre-collision systems include a warning system for backing up that uses rear-facing cameras [46], and a human-machine interface (HMI) for a backing up warning system [47]. Other reports include the application of model predictive control laws to following control in Adaptive Cruise Control (ACC) [48], and descriptions of automatic steering [49][50].

Recently, automakers have also focused on ultra-compact electric vehicles for travelling short distances at medium to low speeds in urban areas and the like. The application of active safety and driver support systems to these vehicles has been studied. Consequently, one report described an automatic driving system using a sensing system that incorporated laser radar and cameras [51]. Pedestrian collision avoidance systems, automatic lane-following controls, and the like have also been installed into such ultra-compact electric vehicles. Furthermore, field tests and the like have been implemented into on-demand automatic transportation systems in areas where high-density platoon driving is possible or in mountainous regions and other areas inconvenient for transportation with a high proportion of elderly residents [52].

The future is likely to see further advances in vehicle control and sensing technology, as well as the dramatic expansion of systems in this field as costs come down. These trends are also likely to progress with ultra-compact electric vehicles as well as with heavy-duty and passenger vehicles. These basic technologies may well form the foundation of innovative traffic systems in the future.

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