ELECTRIC EQUIPMENT

1 Introduction

The environment surrounding automobiles is changing rapidly, placing increasing demands on automobiles, as means of transportation, to offer advanced functions and improved performance in the areas of environmental impact, safety, security, convenience, and comfort to help realize a society that is safer, as well as more secure, sustainable and affluent. Responding to the environmental changes and growing diversification of needs exemplified by the electrification of vehicles, the practical application of connected cars and automated driving technologies requires the construction of new services and structures, as well as an evolution of the means of movement and transportation themselves. Vehicle-mounted electric equipment will play a major and central role in realizing these goals, and innovation and progress in related technologies will have critical importance.

The ongoing strengthening of fuel economy and exhaust emissions regulations aimed at reducing energy and fossil fuel consumption, as well as greenhouse gas emissions, continues to drive the electrification of vehicles. Electrified vehicles, such as hybrid vehicles (HEV) and fully electric vehicles (EV), have continued to grow in number and popularity, and fuel cell vehicles (FCV) have also been introduced to the market, illustrating the active technological development covering all aspects of electrification.

However, conventional engine equipped vehicles are expected to continue to account for the majority of vehicles on the road for the time being, so further reductions in fuel consumption of engine and the development of technologies around engine, including the drivetrain and energy regeneration systems, are being actively pursued. Engine technologies, such as higher compression ratios, higher pressures within the cylinders through supercharging, increased application of exhaust gas recirculation (EGR), and lean combustion have been developed in an effort to make the engine itself more efficient, resulting in the need for a more sophisticated and diversified level of performance from the ignition system.

Other equipment around the engine, such as energy regeneration systems that regenerate vehicle kinetic energy during braking and start-stop systems are now becoming standard equipment on some vehicles. Generators are also continuing to evolve beyond just generating electric power for the vehicle, with integrated starter generators (ISG) and belt starter generators (BSG) being increasingly used as a source of drive power as well. The entire system is becoming more diversified and multifunctional in an effort to realize better vehicle fuel economy.

Vehicle air-conditioners have also become highly efficient, reducing the load on the engine. At the same time, they continue to evolve in response to the various needs of more fuel efficient vehicles, as symbolized by the increasing adoption of air-conditioning systems featuring evaporators with a cold storage function for use in vehicles equipped with a start-stop system. The issue of ensuring a sufficient source of interior heating in highly electrified or fully electric vehicles is addressed by installing a high heating efficiency heat pump system, and steady progress is being made in other improvements in system features and performance.

Electric power steering (EPS) systems are also increasingly being equipped on more and more vehicles around the world since, like the highly efficient air-conditioning systems, they also contribute to better vehicle fuel economy.

In terms of vehicle safety, the number of fatal accidents and associated injuries has been decreasing in Japan due to the advancement and spread of active safety, driving support, damage mitigation, and other technologies. However, existing technologies will have to evolve even further and be reduced in cost to achieve greater

reduction traffic accidents. New products, such as electronic mirrors, are also expected to become available. In contrast, traffic accidents involving elderly drivers are on the rise, prompting the government to accelerate efforts to formulate safety measures, such as the wider adoption of automatic braking systems, aiming to prevent these accidents. The same situation can be observed outside Japan, where the examination and discussion of regulations and mandatory requirements for advanced safety technologies currently underway are expected to expand in the future. In addition, vehicles featuring automated driving systems enabling them to drive themselves under limited conditions are already being sold, but accidents involving these vehicles have been reported. Guidelines and regulations concerning the practical application of automated vehicles are being prepared, and these activities are expected to intensify in conjunction with the development of related technologies and equipment.

Vehicle comfort and convenience remains critically dependent on the amount of information from both inside and outside of the vehicle that can be used. Consequently, the adoption of in-vehicle information and audio systems that communicate with smartphones will only continue to expand. There are also continuing examinations and debate about mandatory requirements for, and the dissemination of, vehicle external communication equipment, such as vehicle-to-everything (V2X) communication. It is expected that vehicle convenience and comfort will be improved even further by capitalizing on various information sources. As a result, the amount of data handled within the vehicle is increasing dramatically and the multiplex communication system is becoming larger and more diversified, a trend that is only expected to continue in the coming years.

2 Technological Trends in Automotive Electric Equipment

2. 1. Electric Equipment for Charging Systems

The never ending demand for stricter fuel economy and exhaust emissions regulations has made the adoption of vehicle kinetic energy regeneration systems and start-stop systems standard practice. High output and highly efficient alternators are now also required to address the rising demand for electrical power in vehicles resulting from the increased amount of on-board electrical equipment and the growing capability of energy recovery.

Various measures to increase the output and efficiency of the alternator are being examined. These include increasing the density of the stator winding, mounting a magnet on the rotor to reduce the leakage flux, modifying the heat dissipation fins to help improve the cooling performance of the rectifier, and replacing the rectifier diode with a high efficiency element, such as a MOSFET, to reduce power consumption. The number of stator winding phases has also been increased (from three to six) in an effort to reduce noise.

The adoption of pulse width modification (PWM) signal, Local Interconnect Network (LIN) communication, or other bidirectional communication interfaces, for the alternator has made it possible to achieve optimal amount of power generation and high-efficiency operation via fine-grained control from the upstream controller.

New regenerative braking systems that use lithium ion batteries and capacitors instead of ordinary lead storage batteries have also become available. Efficient use of this regenerative energy contributes to better driving performance and improves the fuel economy. Some systems use an integrated starter generator (ISG) or belt starter generator (BSG), which have a structure similar to that of an alternator, not only for electric power generation, but also as a source of driving force. These allow for quiet engine restarts, and the use of the regenerative energy by drive assist functions improves fuel economy. Furthermore, Europe has established a 48 V standard, and has a trend of 48V of supply voltage.

2. 2. Electric Equipment for Starting Systems

The number of pieces of auxiliary equipment around the engine is increasing to improve fuel economy which, in conjunction with downsized engines and more expansive vehicle interiors, is resulting in very dense engine compartments. Consequently, there is ongoing demand for smaller and lighter starters.

The number of vehicles equipped with a start-stop system is also continuing to increase due to ever stricter regulations and a growing demand for improved vehicle fuel economy. The use of a start-stop system greatly increases the number of times that the engine is started, and this dramatic increase us compared to a conventional starter, requires modern starters to have excellent durability.

To maximize the amount of time that the engine is stopped and improve vehicle fuel economy, manufacturers are examining the practicality of lengthening the

time that the fuel supply is cut off by stopping the engine during coasting, which is immediately before the vehicle comes to a stop or when it is already moving due to inertia. Adopting this function would further increase the number of times that the engine is started, requiring the starter to be even more durable. This in turn raises a host of other issues, such as shortening the wait time between when the engine is stopped and restarted, smooth starting, and reducing the engine starting noise, which are now all being examined to find solutions.

2. 3. Electric Equipment for Ignition Systems

The ignition system generally consists of ignition coils and spark plugs located on each cylinder, and angle sensors located on the crankshaft or camshaft. Engines with highly efficient operation have become possible through the application of higher compression ratios, supercharging, increased application of exhaust gas recirculation (EGR), and lean combustion. However, this needs stable combustion in a non-combustible environment, and the demand for higher-energy ignition has increased.

Ignition coils are increasingly shifting away from plug-hole coils, in which the winding wire is contained in the plug hole of the engine, to plug-top coils, which have high efficiency magnetic circuit and high flexibility for the high voltage circuit.

Manufacturers are developing spark plugs which have thin and consumption-resistant electrodes for high efficiency and high energy ignition. In addition, as demand for more space-saving designs increases, spark plugs with a M12 thread diameter have become mainstream, and spark plugs with a M10 thread diameter are also coming into use.

The most commonly used angle sensor is a digital output sensor that can be installed directly to the engine, has high signal detection accuracy, signal controllability, and installability. It has become quite important to improve the engine restartability from a turned off condition such as start-stop system. Therefore, angle sensors with a direction of rotation detection function have been adopted so that the angle can still be accurately detected even if the crankshaft reverses when the engine is stopped.

In addition, an ion current detection system which detects the ion generated in combustion is also being put into practical use to help realize more advanced combustion control.

New ignition systems such as multiple, plasma, laser, or other types of ignition are being developed to further improve the efficiency of the engine. Electric equipment related to the ignition system is considered an important technology that will play a key role in developing more environmentally-friendly engines.

2. 4. HVAC Equipment

Innovations are required of HVAC systems in response to new regulations on refrigerants as well as to the major changes being applied to powertrains to address environmental issues.

Vehicles equipped with a start-stop system have become more common, and HVAC with cold storage evaporators that store cold air while the engine is running and use it to cool the cabin when the engine is stopped have been commercialized. The number of models equipped with these systems continues to increase. Since they have no engine serving as the HVAC heat source, electric vehicles previously relied on electric heaters to supply warm air, but these vehicles are now equipped with highly efficient heat pump systems to avoid a reduction in cruising range caused by the increase in electrical load. Nevertheless, ensuring heating performance in regions with extremely low outside temperatures remains an issue, and improvements in that performance is being pursued through the study of systems that recover waste heat from inverters, motors and batteries, or that rely on gas injection technologies capable of improving the performance of the heat pump cycle itself. Some of these technologies have already been commercialized.

Until recently, the refrigerant HFC-134a was used as the main replacement for certain specified chlorofluorocarbons (CFCs). However, this refrigerant also has a large global warming potential (GWP) and the European Union (EU) issued a European Directive that made it mandatory for all new vehicle models sold in and after January 2013 to use a refrigerant with a GWP of less than 150. As a result, a new refrigerant called HFO-1234yf began to be adopted. Despite initial indications that HFO-1234yf could ignite and produce toxic gas in an accident, its safety was confirmed by the European Commission's highest scientific and technological institution in March 2014, and increased adoption of this refrigerant is expected in the future. At the same time, the use of CO_2 refrigerants, which have a lower environmental impact, is also being examined, and some are already being commercialized. However, these refrigerants must be used under high pressure, and the major increase in the

weight and cost of the system still presents a problem.

The large discrepancy between the fuel economy during a driving mode test cycle and during actual use has recently drawn a lot of attention. The effects of HVAC are a major cause of this discrepancy, and taking fuel economy into account during HVAC use is being assessed for the next stage of the fuel economy and emissions test procedure (Worldwide harmonized Light vehicles Test Procedure (WLTP)) that will come into effect in Europe around 2017.

2. 5. Steering Systems

In the global automobile market, vehicles equipped with electric power steering (EPS) account for just under 60% of all vehicles. The number of vehicles equipped with EPS is expected to only keep increasing in the future as fuel economy regulations around the world become stricter and the adoption of driving support systems with EPS steering control, such as lane departure warning (LDW), lane keep assist (LKA), and autonomous emergency steering (AES), continues to expand.

Other trends currently observed in EPS component parts include the coaxial arrangement of the ECU and motor and the accelerated integration of mechanical and electric devices. In addition, the steering angle sensors built into the steering system are now being replaced by EPS rotation angle sensors as part of the growing trend toward smaller parts, reduced weight, and lower costs.

The application of redundancy and multiplexing is also being expanded to peripheral sensors such as torque sensors and rotation angle sensors, in addition to inverters and motor windings, to comply with the increasing sophistication of safety requirements, including the functional safety standard for electrical and/or electronic systems (ISO 26262). As a result, an EPS system capable of continuing to provide steering assist, even in the event of a malfunction, has now been introduced to the market. Furthermore, manufacturers have started to develop an EPS system with a multiplexed microcontroller and power supply in anticipation of the coming era of automated vehicles.

2. 6. Displays and Instrument Panels

Benefiting from the recent advances in display devices, vehicle instrument panels continue to enhance their expressiveness and flexibility to present information. The number of products that use large LCD screens to present expressive, full graphics has already increased. Some manufacturers are also moving toward the use of organic electroluminescence in hopes of eventually attaining even higher definition and lower power consumption.

Vehicle head-up displays (HUD), which project driving support information in front of the driver, also continues to evolve as a means of presenting information more easily through the use of larger display sizes and even augmented reality (AR), which superimposes the displayed information over the landscape ahead. Another trend is the adoption of inexpensive HUD systems that display information on a small plate called a combiner in affordable, mass-production vehicles.

Electronic mirrors are a promising alternative to the current rear- and side-view mirrors on vehicles due to their effectiveness at reducing blind spots, prompting the Japanese Ministry of Land, Infrastructure and Transport (MLIT) to revise the safety regulations in the Road Transport Vehicle Act in June 2016. These revisions allow the rear-view mirror to be substituted with cameras and monitors, and electronic mirrors are therefore expected to become more popular.

2. 7. Multiplex Communication Systems

Multiplex communication systems are growing in scale and complexity as the volume of data handled by vehicles has increased dramatically and connected functions, including automated driving, advanced safety functions, and smartphone integration, continue to evolve and expand.

The current mainstream network topology centers around a relay device called a central gateway to which the various communication buses for the control, body, and information systems are connected in a star configuration. Depending on the application, a controller area network (CAN) or a local interconnect network (LIN) is often used. More recently, however, higher-speed communications methods such CAN-FD, which extends the conventional CAN and only increases speed in the data region, or in-vehicle Ethernet, are increasingly being adopted. Ethernet is being introduced for the Diagnostics over Internet Protocol (DoIP) standard for diagnostics and vehicle-mounted cameras, but its application is also expanding to control and infotainment systems.

At the same time, measures applying to a wide range of layers from the physical to the application layer, including message authentication and IP filtering, are being examined and introduced to enhance information security.

2. 8. On-board Information Systems

The number of vehicle navigation systems shipped in Japan in 2016 was 5.57 million units, an increase of 5.7% compared to the previous year. The majority of the navigation system market, some 98% of the total, is made up of flash memory-based products (calculated from JEITA statistical data).

The number of on-board information systems that can interact with smartphones continues to expand, and at the same time, the number of traffic accidents due to the use of smartphones while driving also shows no signs of decline. In response to this, the National Highway Traffic Safety Administration (NHTSA) in the U.S. released non-binding guidelines in November 2016.

In Japan, the full-scale introduction of ETC 2.0 has begun, making it possible to receive toll discount service applied in accordance with the route of travel on toll roads.

In the U.S., the NHTSA announced a draft regulation in December 2016 that would make V2X mandatory. If this regulation is enacted, all new vehicles would become DSRC communication-enabled around the year 2023. This would be a major step toward the spread of V2X.

Wireless communication in vehicles in moving from 4G LTE to 5G, and automobile manufacturers and communication equipment manufacturers have formed an association related to 5G. The feasibility of applying V2X communication to vehicles due to the short communication delay of 5G is one of the areas under study.

As vehicles acquire various new means of communicating with external sources, the threat of hacking and the vehicle security are acquiring ever greater importance. Activities aimed at enhancing vehicle security will undoubtedly be pursued even more actively in the near future.

2. 9. Audio Systems

The number of vehicle CD player systems shipped in Japan in 2016 was 2.184 million units, a decrease of 16% compared to the previous year. This constitutes an accelerated continuation of the downward trend from 2015, when shipments of 2.60 million units represented a 12% decrease over the previous year (data from the Japan Electronics and Information Technology Industries Association (JEITA)).

In contrast, the demand for linkage functions for portable information device that enable the operation of smartphones and portable music players from on-board devices continues to rise. Currently, Bluetooth is the main form of wireless communication used to connect to these portable information devices, and the dissemination of non-contact charging technologies to supply them with electrical power is also predicted to grow.

In terms of the broadcasting system, satellite radio and hybrid digital (HD) radio are still gaining market share of in North America. In Europe, the promotion of the transition to digital radio by various national governments is speeding up efforts implement the sending and receiving of digital broadcasts and digital audio broadcasting (DAB). The installation rate of digital broadcasting receivers is also predicted to continue to increase in the future.

Audio systems with display screens are now often used to provide driver support when parking. In addition, interaction with smartphones, enabling them to play back and display internet radio content, traffic information, and video data, is also growing in popularity, and these functions will certainly be enhanced and evolve even further. These audio systems are now often equipped on more affordable, mass-production vehicles as well, so it is predicted that their share of the vehicle infotainment device market will continue to increase.

2. 10. Safety Equipment

In 2016, there were 3,904 fatalities and 619,000 people injured in traffic accidents in Japan (data from the Japanese National Police Agency). This was the first time since 1949 that the number of traffic fatalities had dropped below 4,000 people. However, reflecting the aging of Japan's population, the number of traffic accidents involving the elderly is increasing. In December 2016, MLIT requested that manufacturers of light vehicles formulate safety measures, such as increasing the use of automatic braking systems, to help prevent accidents by elderly drivers. In addition, products that can be retrofitted to existing vehicles and prevent elderly drivers from pressing the wrong pedal have also been commercialized, indicating the growing concern in society with respect to preventing traffic accidents among the elderly.

Looking outside Japan, the European Commission has proposed nineteen types of advanced safety technologies for eventual installation in vehicles, and it is now examining the possibility of making them mandatory. The main EU road safety regulations, namely the General Safety Regulation (GSR) and the Pedestrian Safety Regulation, are scheduled for review based on the results of those

examinations.

In the U.S. twenty automobile manufacturers signed a voluntary agreement on automatic emergency braking (AEB) systems in March 2016, and almost 100% of new cars in the U.S. are scheduled to be equipped with AEB by 2022. In addition, NHTSA and the National Safety Council (NSC) have partnered to form the Road to Zero Coalition, which seeks to identify measures that will eliminate traffic fatalities within 30 years. They are now planning out their long-term roadmap of activities in the areas of driver behavior, roadway infrastructure, vehicle safety, and emergency medical services.

A lot of attention in society is now being focused on automated vehicles, and several vehicles that can drive themselves automatically under limited conditions have been launched by multiple automobile manufacturers. However, fatal accidents involving vehicles driving in an automated driving mode have occurred in North America and multiple examples of accidents involving automated vehicles during demonstration testing on public roads have also been reported. Given these circumstances, the U.S. Department of Transportation formulated and issued guidelines for the development of automated vehicles in September 2016.