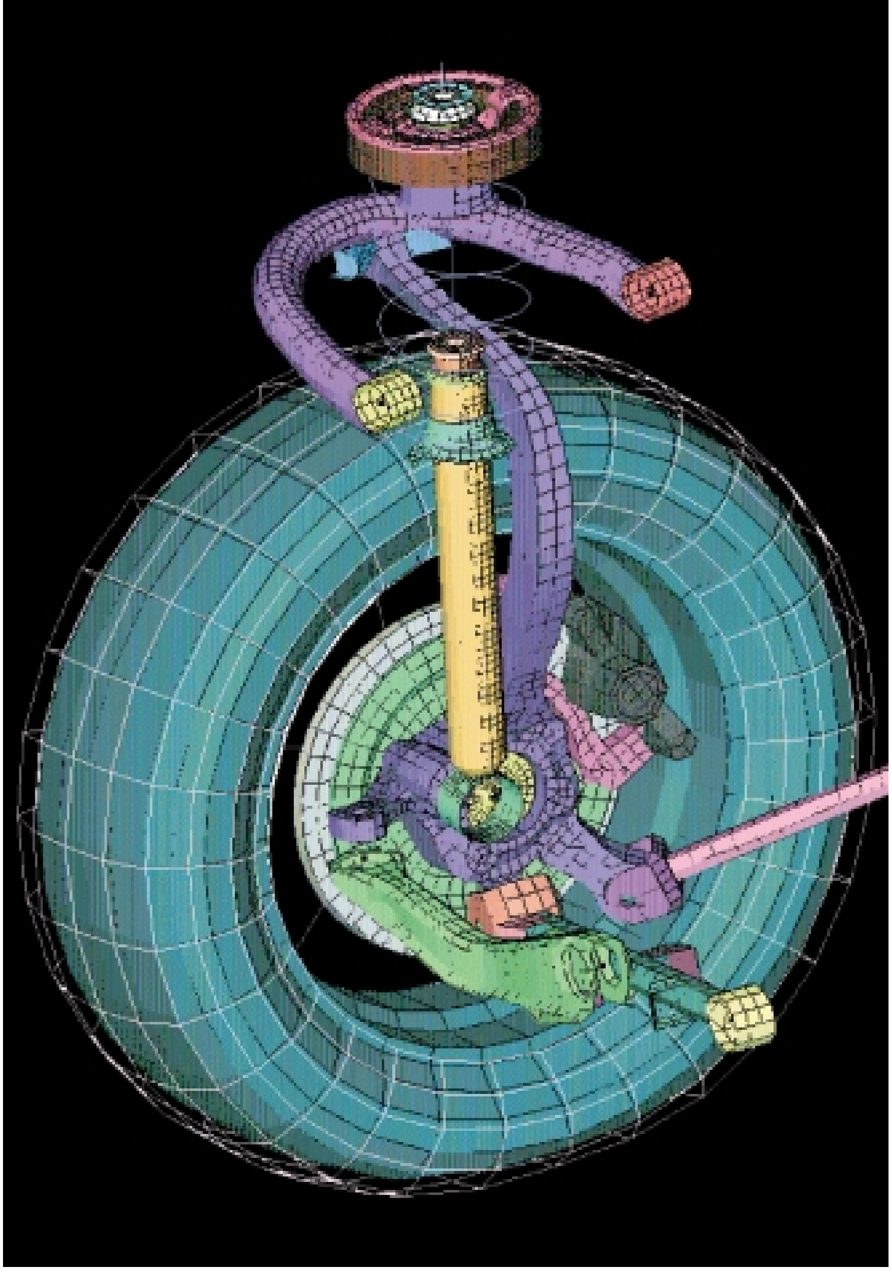

TECHNICAL REVIEW

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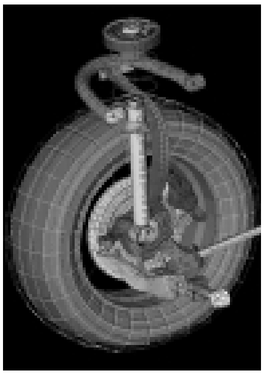
MITSUBISHI MOTORS



- **Cover Photograph**

The cover photograph shows a finite element model of the rear tire and the rear multi-link suspension of the Mitsubishi GALANT. The tire, the wheel, the air in the tire, the suspension arms, the bushing, the shock absorber and the brake system are modeled. The tire characteristics are modeled taking into account the loading applied by the vehicle weight. And by modeling the air in the tire, cavity-resonance noise is able to simulate. Finite element model also enables to verify easily the effect of structure modification.

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Photo in the previous page
At the 2005 Dakar Rally (Paris-Dakar Rally), the final leg was fought on January 16, when Mitsubishi PAJERO EVOLUTION driver S. Peterhansel won the second consecutive victory. MMC achieved five successive championships in the Dakar Rally for the first time in the history, and it was the 10th triumph for MMC. The photo shows the sprinting by Peterhansel and Alphand who came second.

Quality Thesis

New Products

Technological Development that Provides "Driving Pleasure and Assured Security"s to Customers

Tetsuro AIKAWA
Senior Executive Officer,
In Charge of Product Development Group Headquarters

The Kyoto Protocol became effective in February this year, and efforts to prevent global warming thus made a significant stride forward. While the Automobile Recycling Law was enacted in January 2005 in Japan, the shortage of steel has continued since last year. These facts require manufacturers to acknowledge once again the importance of environmental protection and the value of resources and to accelerate improvement of their fundamental technologies and systems.

In January this year, Mitsubishi Motors Corporation (MMC) announced a new corporate philosophy to underpin its revitalization plan: "MMC is dedicated to responsibly providing customers and society with driving pleasure and assured security". "Driving pleasure and assured security" are not only necessary to realize product DNA in "Sporty DNA, SUV DNA", but are important keywords at the core of MMC's product manufacturing to recover customer trust and contribute to society.

We have accumulated technologies that deliver "driving pleasure". Last year, our globally deployed LANCER EVOLUTION won the "Sports Car of the Year" award in a professional magazine in France, a clear indication of its high evaluation overseas, and the European-produced COLT also won the "Golden Steering Wheel Award" for compact vehicles in Germany last year. Winning this prize in Europe, where emphasis is placed on driving performance as well as on design and utility, is firm evidence that the "driving pleasure" of our most basic product is recognized.

Beginning with the COLT, MMC has developed a new-generation engine series that is lightweight, compact and high performance. MMC will successively launch new 4-cylinder and 6-cylinder models, and deliver "driving pleasure" with the new power plant that boasts both power and environmental performance.

In addition to the engines, MMC will reduce the weight and increase the body rigidity, improve basic functions such as suspension and steering, refine its outstanding 4WD technology and offer comprehensive control of all of these operations. Through these improvements, MMC will offer "driving pleasure" as well as true "dynamic safety" to our customers.

The remarkable results at the Dakar Rally, FIA World Rally Championship (WRC) and other rally fields plus the feedback from these experiences are a great asset. The five successive championships of the Dakar Rally demonstrated the new technologies and know-how of our problem-solving skills. Application of those technologies and expertise to commercial vehicles will help create "driving pleasure" that is unique to MMC. We should offer these together with "assured security" to all our customers, of course, not only to some but also to females and seniors.

"Assured security" means safety, durability and reliability in the technical aspects, and ease of use and comfort in a broader sense. From a global view, MMC offers one of the longest warranty periods in the business. We will continue to prolong the life of vehicles with improved materials, structures and other means. And longer product life also benefits the environment.

For safety, in addition to the traditional active safety and passive safety, we will continue research and development on damage reduction technology by crash forecasting and on driving support technology with our electronic technology, and will promptly introduce these technologies to our products for our customers' convenience.

It is also important that customers actually feel the "assured security" not only at emergencies but also in daily usage, such as through leading technologies for automated equipment and devices to prevent error or theft.

We are placing a high importance on 'assured security' backed by accumulation of these fundamental technologies so as to provide our customers feeling of security.

We cannot forget the efforts for environmental and energy-related issues in addition to the "driving pleasure and assured security" that are at the heart of our products. For instance, we will continue to develop advanced platforms in consideration of the future fuel-battery vehicles and hybrid vehicles based on our fundamental technologies on lithium ion batteries and high-performance motors.

MMC had been facing a quick succession of its partners in management and technologies in the past several years. However, the automobile technologies are to be developed and shared with global partners, individual companies' characteristic technologies and the technologies that integrate them into products. We must develop original, focused technologies and integrate them within a limited resource base. This is our direction and we would like to put up new philosophy here, "driving pleasure and assured security".

Finally, this MITSUBISHI MOTORS TECHNICAL REVIEW introduces our past achievements and future prospects to further evolve the direction and technological DNA of MMC. We would be most happy if you could read it carefully to gain an understanding of the direction of our future technologies.

Thank you.

TECHNICAL PERSPECTIVE

Technology DNA of MMC

Toru HASHIMOTO* Kazuo FUKUYAMA*
Nobuhiro OIKAWA* Tateo KUME**

Abstract

The technology DNA of Mitsubishi Motors Corporation (MMC) is based on MMC's excellence in three areas: engine technologies, which we originally learned from the demanding field of aircraft development; vehicle-dynamics technologies, which we refine through participation in rallies under severe driving conditions; and packaging technologies, through which we offer customers new lifestyle possibilities and added value. MMC must continue to make advances in all these areas as it builds a strong brand identity.

Key words: *DNA, Engine, Vehicle-Dynamics, Packaging, Brand*

1. Introduction

MMC's history of vehicle development began in 1917 with the Mitsubishi Model-A, Japan's first mass-production passenger car (**Fig. 1**)[(1)]. Twenty-two units of the Mitsubishi Model-A were made through 1921 – a period in which there were very few cars in Japan. (The only other cars in Japan were imported from Europe and the United States.) Mitsubishi established itself as Japan's pioneering automaker, going on to develop models such as the Mitsubishi PX-33 in 1937, which was Japan's first full-time four-wheel-drive (4WD) vehicle.

From its earliest days, the Mitsubishi automaking operation has had a close relationship with the aircraft-development division of Mitsubishi Heavy Industries; many aircraft-related technologies have been put to effective use in Mitsubishi vehicle development. Since any technological problem in an aircraft directly impacts the lives of occupants, the level of technological excellence demanded of aircraft is far higher than that demanded of vehicles. For example, an engine fault can prevent an aircraft from staying in the air; poor fuel efficiency can limit an aircraft's flying range, rendering the aircraft unable to return to base; and in the case of a fighter aircraft, poor power performance can limit speed and altitude, putting the aircraft in danger of being shot down. In other words, aircraft need superior durability, reliability, fuel efficiency, and power performance. MMC has applied the same uncompromised standards to engine development for vehicles. The benefits have been reflected in numerous industry-leading technologies such as the MCA-JET system[(2)] (a unique lean-combustion technology that realized superior fuel efficiency plus early compliance with Japan's 1978 exhaust-emission regulations – the world's most stringent exhaust-emission regulations at the time); performance-enhancing turbocharging technologies and valve timing control technologies (including the MIVEC engine); and the GDI engine (a gasoline direct-injection system enabling incomparably low fuel consumption).

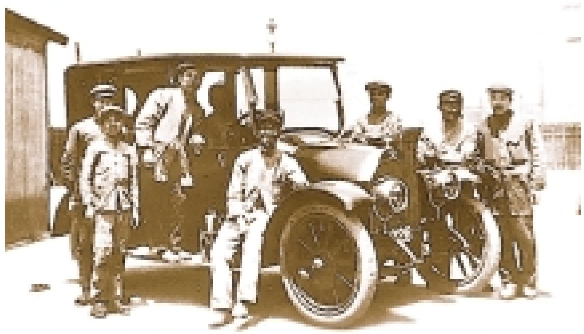

Fig. 1 Mitsubishi Model-A

These technologies are behind MMC's reputation for excellence in the field of engines.

Aircraft technologies have also been put to good use in areas of Mitsubishi vehicle development other than engines. Notably, the Mitsubishi 500 (**Fig. 2**), which went on sale in 1960, had superior aerodynamic performance because it was the first Japanese vehicle to be developed with the aid of wind-tunnel tests. In 1962, the Mitsubishi 500 was the first Japanese car ever to race in the Macao Grand Prix, where it took first, second, and third places in Class A (up to 750 cc). This race victory marked the start of a glorious Mitsubishi motorsports heritage. MMC won the 7th Southern Cross Rally in 1972 and went on to win the Southern Cross Rally in each of the four following years. And since then, other MMC vehicles including the LANCER EVOLUTION and PAJERO have demonstrated MMC's technological excellence through victories in the FIA World Rally Championship, Dakar Rally (**Fig. 3**), and other rally competitions around the world. Competing in the severe driving conditions imposed by rally competitions has, over the years, enabled MMC to refine the vehicle-dynamics technologies that form part of its technology DNA.

Further, MMC has proved itself a concept leader by continuously anticipating the needs of motorists and

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Fig. 2 Mitsubishi 500

Fig. 3 MMC's victory in the 2005 Dakar Rally

developing new kinds of vehicles suited to contemporary lifestyles. MMC's leadership in this area is exemplified by the first-generation MIRAGE, in which MMC was an early adopter of the front-engine front-wheel-drive (FF) configuration on which most compact cars are now based, by the RVR and SPACE GEAR, through which MMC offered consumers new ways to spend their growing leisure time, and by the PAJERO, a full-fledged Sports Utility Vehicle (SUV) that makes off-road driving easy and enjoyable. The packaging technologies behind these industry-leading offerings form, like MMC's engine technologies and vehicle-dynamics technologies, a core element of MMC's technology DNA.

Expectations for MMC's future engine, vehicle-dynamics, and packaging technologies are discussed hereafter.

2. MMC engine technologies

The role of an engine is to efficiently convert the chemical energy of fuel into kinetic energy. Efficient conversion of fuel's chemical energy into kinetic energy is dependent on how well a large amount of fuel can be introduced in a unit period of time and used to produce power (for high output) and on how well the introduced fuel can be converted into energy (for high fuel efficiency). Other demands include low weight (essential for high dynamic performance); low vibration and noise (essential for comfort); and low emissions, high durability, high reliability, low cost, low energy consumption during production and operation, and high recyclability (all essential for social acceptability).

Particularly since the 1992 United Nations Conference on Environment and Development, growing environmental concern has prompted diversification of vehicle powertrains. Vehicles available now include not only internal-combustion-engine vehicles but also hybrid vehicles, and in smaller numbers, electric vehicles and fuel-cell vehicles. Nevertheless, internal-combustion-engine vehicles remain dominant, with the market divided between those with gasoline engines and those with diesel engines. In Japan and the United States, gasoline engines are more prevalent owing partly to their compactness and lightness and partly to the relative ease with which they can be made to deliver high power with low emissions. In Europe, by contrast, diesel-engine vehicles have, owing to their economical operation, become popular to the extent that they account for about half of newly registered passenger vehicles.

It is difficult to predict what form of vehicle powertrain will be most prevalent in the future. But in light of ongoing armed conflict and political instability in the Middle East, increasing crude-oil prices that are accompanying rapid growth of energy consumption in developing countries, and ongoing tightening of fuel-consumption regulations in industrialized countries, any attempt at prediction must conclude at least that thermal efficiency will be increasingly crucial.

Gasoline engines are characterized by high power density but suffer relatively low thermal efficiency when partially loaded, so efforts to improve efficiency in gasoline engines have thus far focused on increasing partial-load thermal efficiency while maintaining or increasing power density. MMC took a major step forward in 1996 with the development of the GDI engine, the world's first volume-produced lean-burn direct injection gasoline engine (**Fig. 4**). MMC's GDI technology was hailed inside and outside Japan as the ultimate means of overcoming the inherent shortcomings of gasoline engines. The higher thermal efficiency yielded by GDI technology prompted some observers to comment that there was no longer any need for passenger-car diesel engines; it triggered the subsequent advance from indirect-injection diesel engines (the type of engine that had been prevalent in diesel passenger cars) to direct-injection diesel engines. Diesel engines have since shown great advances in power, thermal efficiency, and emissions performance owing to high-pressure direct injection (made possible by electronically controlled common-rail fuel-injection technology) and to high boost pressure (made possible by advanced turbochargers). In fact, the most important advantage of gasoline engines, namely the ease with which load control can be effected using throttle valves, has come to be seen as less of an advantage since the pumping losses caused by throttle valves are hindering improvements in gasoline engines' thermal efficiency. To remedy this situation, it is urgently important to eliminate the factor that is hindering improvements in gasoline engines' thermal efficiency. In other words, gasoline-engine developers are likely to pursue higher thermal efficien-

Fig. 4 GDI engine

Fig. 5 New-generation engine

cy using throttle-valve-less designs while seeking further improvements in gasoline engines' inherently high power density.

With diesel engines, low power density, which has been seen as a major inherent weakness, has been overcome by direct fuel injection and turbocharging. And other shortcomings of diesel engines, namely their high vibration and noise and the difficulty of suppressing their nitrogen-oxide and particulate-matter emissions, have been resolved in large part by common-rail fuel-injection technology. As direct-injection technology becomes more advanced, concomitant improvements in fuel efficiency will likely drive further improvements in emissions performance.

As internal-combustion engines become more advanced and efficient, further increases in overall efficiency can be expected as internal-combustion engines are combined with continuously variable transmissions (CVT), automated manual transmissions, and other new power-transmission systems.

Hybrid vehicles, which combine internal-combustion engines with electric motors for superior overall efficiency, are attracting attention. However, hybrid systems are complex and are heavier and more costly than internal-combustion engines, so it is unlikely that hybrid vehicles will completely displace internal-combustion-engine vehicles. It is more likely that gasoline engines, diesel engines, and hybrid systems will co-exist as their respective technologies continue to evolve.

Beginning with the new COLT, which went on sale in Europe in April 2004, MMC has been introducing new-generation engines (**Fig. 5**) across its entire vehicle range to replace existing three-cylinder mini engines, four-cylinder small and compact engines, and six-cylinder gasoline engines. The most important features of each of the new-series engines are an aluminum cylinder block and a MIVEC valve timing control system. The lightness of the cylinder block promotes the fundamental running, turning, and stopping aspects of dynamic performance. At the same time, the MIVEC system controls the volume and flow pattern of air drawn into each cylinder. The controlled intake flow optimizes combustion such that high efficiency and high power are simultaneously realized throughout the rev range and such that emissions can potentially be kept within the limits imposed by increasingly stringent regulations. In addition to these structural merits, MMC's new-series engines reflect comprehensive efforts to minimize frictional losses, maximize rigidity, and optimize clearances between sliding parts. The resulting benefits in high power, low fuel consumption, and low noise and vibration translate into performance befitting next-generation gasoline engines.

With its new-generation gasoline engines forming the core of its efforts, MMC will, notwithstanding powertrain leadership challenges posed by diesel engines and hybrid systems, continue to refine and advance the engine technologies that form a key part of MMC's technology DNA, thereby retaining its competitive edge.

3. MMC vehicle-dynamics technologies

High dynamic performance can be defined as the ability of a vehicle to behave safely and precisely in accordance with the driver's wishes in diverse operating environments. More specifically, it can be defined as the ability of a vehicle to continuously remain stable while making maximal use of the force that acts between the tires and the road surface.

Dynamic performance defined in these terms was originally refined through improvements in vehicles' basic specifications and suspension mechanisms, but since the mid-1980s chassis-control technologies such as electronically controlled suspension (ECS) systems and four-wheel steering (4WS) systems have realized more marked improvements.

MMC is a pioneer in this field. In addition to making advances in four-wheel independent suspension and other fundamental chassis technologies, MMC developed the world's first active ECS system (a means of actively controlling a vehicle's cornering attitude and dynamic performance) and adopted it in the 1987 GALANT. MMC's active ECS system not only enhanced ride comfort; it also kept body inclination to a minimum under all driving conditions and thus optimally controlled the grip between the tires and the road surface. The 1987 GALANT also incorporated a 4WS system that caused the rear wheels to exert lateral force sooner than with conventional steering, resulting in markedly improved yaw-direction stability at high vehicle speeds. These MMC technologies realized high dynamic performance in driving environments where it could not be realized with earlier technologies. In this sense, they greatly changed the concept of driving safety.

Development of electronic control technologies for suspension and steering subsequently slowed. From the mid-1990s, developers turned their attention mainly to high-cost-performance forms of braking control. MMC led the industry with the development of technologies that enabled a vehicle's yaw motion to be con-

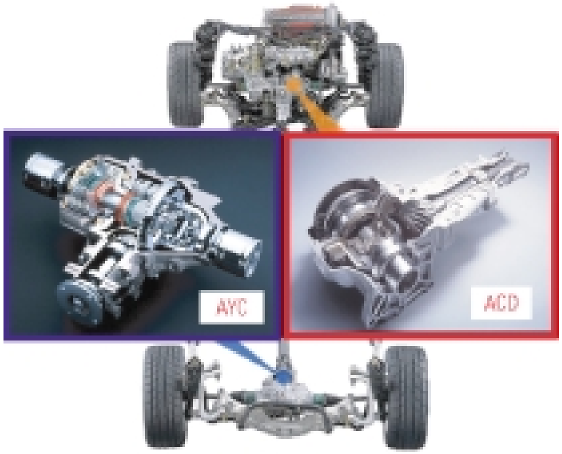

Fig. 6　AYC system

trolled by means of powertrain components, and in 1996 MMC incorporated these technologies in the GALANT and LANCER EVOLUTION in the form of the world's first active yaw control (AYC) system (**Fig. 6**), which promoted and controlled the vehicle's yaw moment as necessary by optimally controlling the torque difference between the left and right rear wheels. More recently, attention has been focused on stabilizer-control technologies that provide the roll stiffness that is required during cornering maneuvers. With SUVs and other vehicles with high centers of gravity, such technologies are effective both at preventing excessive roll movements and at enhancing rough-road drivability. MMC has proven its value in the PAJERO in the Dakar Rally.

In the years ahead, further advances in torque-control technologies, further advances in electronically controlled braking systems (namely active stability control systems and anti-lock braking systems), further advances in electronically controlled steering systems, and new combinations of these technologies can be expected to yield even more sophisticated and effective means of controlling vehicles' dynamic performance.

Recent demands for increased cabin space have caused vehicles to be made with greater overall lengths and heights, with the result that vehicle inertia moments are also tending to increase. This trend is disadvantageous from the point of view of dynamic performance. An effective countermeasure is to make components that are far from a vehicle's center of gravity as light as possible, thereby effectively lowering the center of gravity. MMC's success in this regard is exemplified by the LANCER EVOLUTION MR, in which MMC used aluminum not only for the hood but also for the roof, thereby achieving a low inertia moment and concomitantly high dynamic performance. A further benefit of such weight-saving techniques is significantly improved fuel economy.

Vehicle-dynamics technologies also aim more safety driving. Although passive-safety technologies realize significant reductions in fatalities caused by traffic accidents, active-safety technologies, which are intended to enable drivers to avoid collisions, are attracting worldwide attention. Vehicle-dynamics technologies are inextricably linked with active safety. In Europe, a Primary New Car Assessment Programme (a programme intended to enable independent assessment of active-safety performance in parallel with the European New Car Assessment Programme that already enables independent assessment of passive-safety performance) has recently been proposed and will likely be a major factor driving further advances in vehicle-dynamics technologies.

Fig. 7　PAJERO

For MMC's vehicle-dynamics superiority to grow into part of a strong brand identity, it is vital for MMC to feed back into its volume-production vehicles the technologies through which it pursues uncompromised driving safety in its rally vehicles. While pursuing improvements in dynamic performance through improvements in terms of lightness, suspension characteristics, body stiffness, and other fundamental attributes of its vehicles, MMC will continue to pursue superior vehicle dynamics through complementary advances in electronic control technologies.

4.　MMC packaging technologies

Packaging defines the interface between a vehicle and the people who use it; it embodies the concept behind the vehicle. Particularly since the 1990s (the period following the bursting of Japan's economic bubble), consumers' priorities have diversified, making packaging an increasingly crucial element in the consumer appeal of any vehicle. MMC is a leader in this regard, having continually led the industry in the introduction of new forms of vehicles taking advantage of new technologies.

With the first-generation MIRAGE, which went on the market in 1978, MMC established the precedent of using the FF configuration for compact cars. This vehicle not embodied the benefits of FF technologies in terms of increased cabin space and lower weight; it was also distinguished by flush surfaces, which improved aerodynamic performance and limited wind noise.

In 1982, the PAJERO (**Fig. 7**) changed the face of off-road vehicles. Until then, off-road driving could be enjoyed by just a small proportion of motorists using Jeeps and other military-style vehicles. With the PAJERO, MMC added comfort to off-road capability, making off-road driving enjoyable for the wider motoring public. Superior visibility provided by a high eye point also contributed to the PAJERO's popularity. The

Fig. 8 DELICA 4WD

Fig. 9 “i”

PAJERO was the spark for the subsequent SUV boom. Also in 1982, MMC launched the DELICA 4WD (**Fig. 8**), in which it added a high-level of off-road capability to a one-box-type vehicle (a kind of vehicle previously seen as limited to commercial use), thereby offering families the new lifestyle option of taking camping gear out to the countryside and mountains to enjoy the great outdoors together. The DELICA 4WD proved popular with many customers. In 1983, MMC developed the CHARIOT, an FF passenger car in which three seating rows enabled a whole family to ride in comfort. The CHARIOT was distinguished also by a high eye point and a concomitantly wide field of driver visibility, which promoted safety. It was instrumental in creating the minivan market segment, which has since become huge. In 1990, MMC launched the convenience-oriented MINICA TOPPO, which offered the easy drivability of a bonnet-type vehicle with the tall cabin of a one-box-type vehicle, and the DIAMANTE, which created a market segment for medium-sized sedans. Then in 1991, MMC launched the RVR, a highly acclaimed model in which a fully flat floor and long-slide seats were combined with neat styling that was made possible by an inner-rail-type sliding door – a further demonstration of MMC’s position as a concept leader that continuously anticipates the needs of motorists and responds with new kinds of vehicles for new lifestyle possibilities.

Today, the car market is broadly divided into sedan, minivan, and SUV categories. Packaging technologies can be expected to continue evolving in each of these categories, and it is likely that packaging proposals for crossover cars that do not fit into any single category will continue to emerge. Packaging engineers must continue striving to create new ways to maximize cabin roominess within limited dimensions while also enabling the incorporation of various powertrains and measures for compliance with increasingly stringent collision-safety regulations. Many technological challenges – these include finding ways to realize pillarless doors (for easier cabin ingress and egress and a stronger sense of openness), diverse seat arrangements that can be selected with a single touch, low floors, and low centers of gravity – remain to be overcome. At the 2003 Tokyo Motor Show, MMC demonstrated its intention to continue addressing these challenges by unveiling the “i” (**Fig. 9**), a new-platform minicar combining outstanding styling with interior spaciousness comparable with that of larger vehicles. With the sportiness and SUV attributes of MMC product DNA at the core of its efforts, MMC will continue to develop packaging for vehicles with new forms of added value in every segment of the market.

5. Conclusion

An automobile is a combination of technologies from wide-ranging fields including mechanics, electrics and electronics, and chemistry, and each automaker attempts to differentiate itself from others by building a brand identity using technologies in which it has particular strength. MMC, for its part, will continue to relentlessly make advances in the three areas (engine technologies, vehicle-dynamics technologies, and packaging technologies) that form the basis of its technology DNA, thereby enabling itself to continue building a strong brand identity and to continue developing and offering vehicles that delight customers.

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CVT Drive Train Vibration Analysis and Active Control System Design

Kazuhide TOGAI* Tadashi TAKEUCHI*

Abstract

With their exclusive drive train structures, vehicles equipped with continuously variable transmission (CVT) have relatively low resonance frequencies and thus are prone to generate annoying vibrations. While CVT-equipped vehicles can be jerky during acceleration, they can also experience "rocky" vibration during speed change caused by load fluctuation as well as "to-and-fro" surging during start-off caused by a torque converter characteristic. This paper attempts to identify causes of these vibrations from the viewpoints of vibration sources, transfer paths and feedback control. Vibration damping can be achieved by taking related actions for vibration sources and also for transfer paths. This paper quantifies vibration damping effects, taking into consideration various constraints associated with the two options. Today, electronic throttles and electronically controlled mounts are available as a means of actuators: vibration damping has been achieved through controlled throttle operation. This paper presents vibration control design that ensures response to driver inputs and minimum performance loss while taking into consideration the frequency characteristics and dynamic range of the entire system.

Key words: *Active Vibration Reduction, Drive Train Torsional Vibration, Torque Converter, Electronically Controlled Mount, Electronically Controlled Throttle*

1. Introduction

On passenger cars, engine torque, which can vary widely (dynamic range and fluctuation synchronous to speed), is transmitted via the drive train, a spring-mass system, to the tires. This causes the vehicle to run. It is widely known that road inputs lead to vibration as they are transmitted from the tires via the suspensions to the body, and that vibration in the steering wheel and seats becomes worse as the idle speed's lowered. On the other hand, it is difficult to intuitively understand the relationship between the power train and vibration as the former is normally not visible. In recent years, CVT has been introduced on a growing number of vehicles to improve fuel economy and comfort. CVT has a larger moment of inertia than automatic transmission (hereafter referred to as "A/T"). Also, on CVT-equipped vehicles, the torque converter more frequently locks up. For these reasons, CVT-equipped vehicles are prone to vibration. This paper describes typical vibrations of CVT-equipped vehicles that are caused by the power train, their causes, and active vibration reduction methods. Vibration that is specific to CVT is caused by the hydraulic control and other vibrations on CVT are common with those of A/T. Also, CVT is similar to manual transmission except that the former operates in conjunction with a torque converter. Hence, many of the descriptions in this paper regarding CVT are also applicable to passenger cars in general.

2. Power train-caused vibrations and their transfer paths

A passenger car is a multiple mass-spring kinetic system, made up of the engine and tires, each having a relatively large moment of inertia. These components are located at the ends of the drive shafts, and are supported by the suspensions and engine mounts. **Fig. 1** shows a typical CVT power train. **Fig. 2** shows a typical spring-mass system layout. Annoying vibrations during start-off, acceleration or deceleration (shock & jerk) are largely attributable to drive train torsional vibrations [1][2]. These vibrations are generated and then transmitted by the power train. A vibration transmission path model, running from the vibration sources to the seats (seat riser), typically consists of a drive train torsion model from the engine to the tires via the transmission, and a vehicle dynamic model that takes into account the mounts and suspensions that transmit drive train torsional vibration to the body. A two-dimensional, non-linear model was formulated[2], which has 10 degrees of freedom in total: One degree of freedom for each of the flywheel, the gears and the tires; one degree of freedom for the suspensions; and three degrees of freedom (longitudinal, vertical and rotational) for each of the power plant and the rigid body. This can be expressed by the following matrix equation, which takes damping into account:

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=\{F\} \qquad (1)$$

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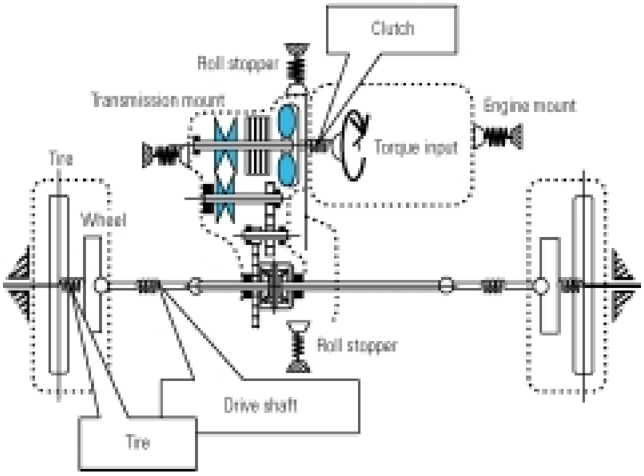

Fig. 1　Power train elements

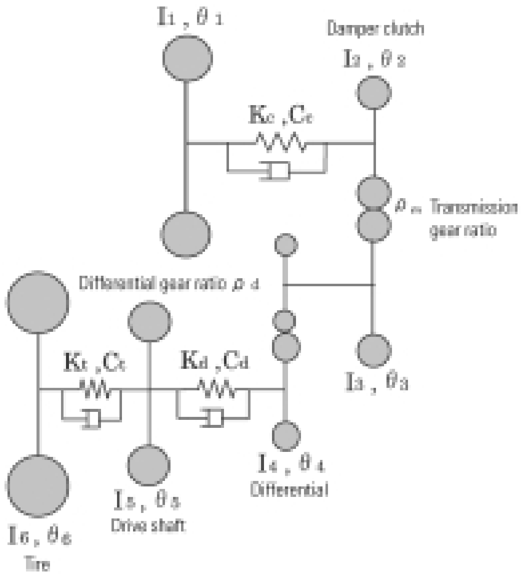

Fig. 2　Drive train torsion model

where
[M]: 10 x 10 inertia matrix
[C] : 10 x 10 damping matrix
[K] : 10 x 10 rigidity matrix
{F} : 10 x 1 force vector
{X} : 10 x 1 displacement vector

The characteristic vibration of this equation is dominated by low frequencies, which are largely attributable to the torsional rigidity of the drive shafts and the moments of inertia of the engine and CVT. Accumulation of energy is also concentrated in these areas. At the same time, due to energy absorption and release caused by speed change during acceleration and deceleration, the driver feels as if the vehicle is accelerating or decelerating irrespective of his/her maneuvering of the accelerator pedal. While the engine torque is transmitted via a complex path before resulting in longitudinal vibration of the body, the waveform of the longitudinal acceleration of the body (or the drive shaft angular acceleration) in response to stepped torque input can, based on the characteristics of the waveform, be approximated as a second-order delayed response (**Fig. 3**). Similar results can be obtained from eigenvalue analysis of the coefficient matrix. The approximation can be expressed using the following equation, with $G(s)$ representing the transmission characteristics of the longitudinal acceleration of the body relative to the torque input.

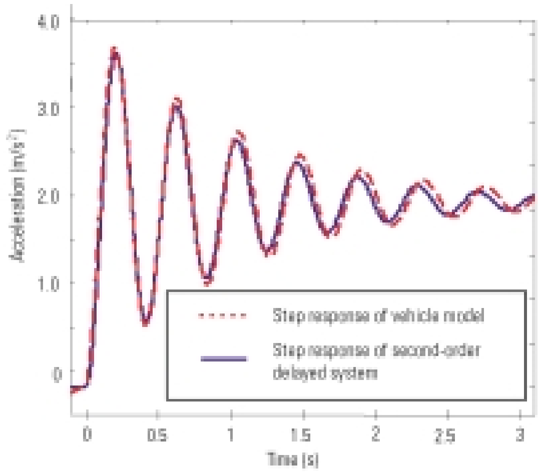

Fig. 3　Approximation of high-order system by second-order system

$$G(s) \approx \frac{K_p \cdot \omega_n^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2} \tag{2}$$

where
K_p : Conversion factor from torque to acceleration
ς, ω_n: Damping coefficient and eigenfrequency (basic order) of longitudinal body vibration

Hereafter in this paper, the transmission system of vibration to the body is presented as a secondary vibration system unless specified otherwise, and the target of vibration reduction control is the range of 2 – 8 Hz, which can be generated on CVT-equipped vehicles.

3. Causes of vibration

Vibrations that are annoying to occupants are caused by several factors, not all of which are attributable to CVT. Vibrations can be substantial on CVT which, due to its design, has a relatively large moment of inertia and low resonance frequencies. Various phenomena, including sudden torque input (load), are now described in the following paragraphs, including their causes.

3.1 Rapid engine torque change

When engine torque rapidly changes during acceleration or deceleration and the torque change is applied

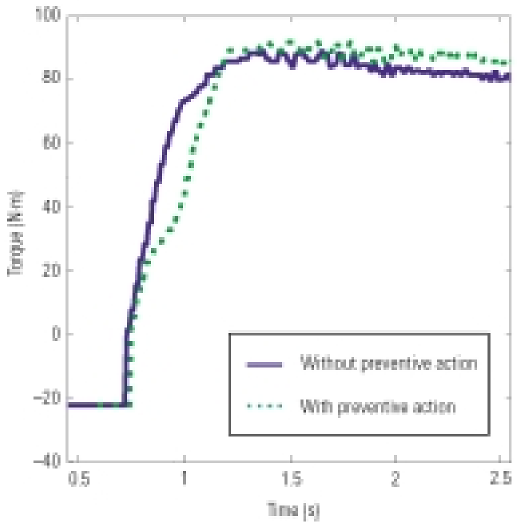

Fig. 4a Engine torque fluctuation

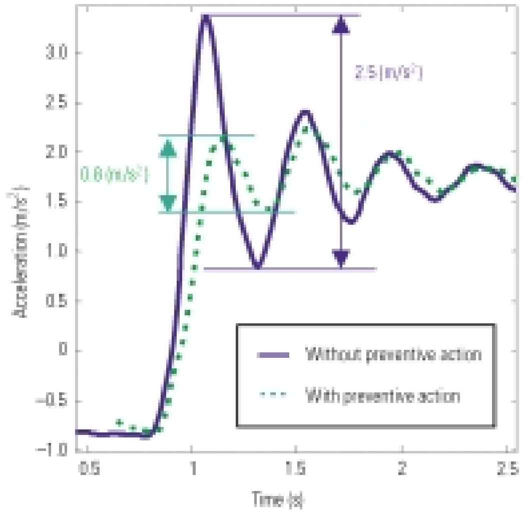

Fig. 4b Acceleration change

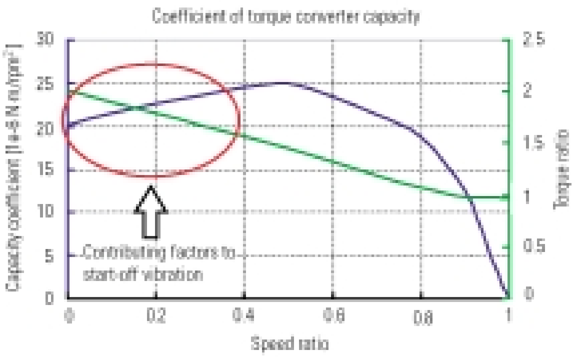

Fig. 5 Torque converter capacity characteristics that contribute to start-off vibration

to the vibration system mentioned earlier, vibration will naturally be generated due to resonance frequency components in the torque waveform. For example, when torque changes in steps, this generates torsional vibration of the drive shaft, which then annoys the occupants in the form of acceleration jerk. On actual vehicles, stepped torque change occurs only on common-rail diesel injection (CDI) engines and gasoline direct injection (GDI) engines. On petrol-powered MPI engines, the cumulative effect of the intake system often tends to blunt the torque waveform in response to accelerator input. If acceleration shock is felt at all, then this is almost always because the lockup clutch has been engaged. **Fig. 4** shows an example of rapid torque increase and the resultant vibration. The example shown, however, is an extreme case and, as described later in this paper, vehicles on the market have features to prevent this.

3.2 Capacity characteristics of torque converter

Fuel consumption testing on vehicles equipped with a torque converter is performed with the torque converter running even in vehicle-stationary engine idle mode. The engine torque under load can be obtained by multiplying the capacity coefficient (C) by the square of speed. Therefore, fuel economy can be improved by reducing the capacity coefficient (C) when the vehicle is stationary (when speed ratio is zero). However, this should not permit the entire capacity characteristics to be lowered, otherwise, starting acceleration will be compromised. In order to achieve both requirements at the same time, the capacity coefficient (C) characteristics, shown in **Fig. 5**, have been employed in which the capacity increases as the speed rises. This leads to self-induced vibration. Conditions that lead to self-induced vibration are shown in **Fig. 6**.

With a torque converter, as the turbine speed picks up, torque absorption increases and the engine speed drops. When the vehicle speed is so marginal such as when starting off, however, the speed ratio is dominated by the turbine speed. With this, torque absorption and torque converter output torque are assumed to be proportional to the turbine speed (ω_t). The transmission input torque is then linearized and can be expressed as $T_{e0} + C_0\omega_t$.

The equation of motion for the drive shafts is as follows.

$$I\ddot{\theta} + D\dot{\theta} + K\theta = \left(T_{e0} + C_0\omega_t\right)\rho$$

As $\dot{\theta} = \omega_t$,

$$I\ddot{\theta} + \left(D - \rho C_0\right)\dot{\theta} + K\theta = T_{e0}\rho \qquad (3)$$

where

I : Moment of inertia on upstream of drive shaft
D : Damping term
K : Torsional rigidity of drive shaft
C_0 : Gradient of C when speed ratio = 0
ρ : Total reduction ratio
T_{e0}: Engine torque
θ : Rotational angle of drive shaft

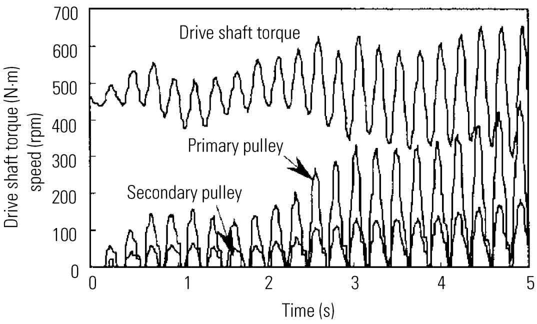

Fig. 6 Self-induced vibration immediately after start-off

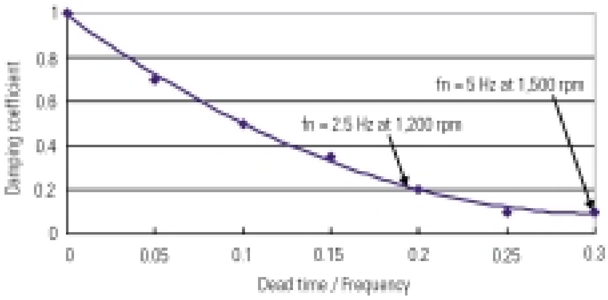

Fig. 7 Equivalent dead time and achievable damping

With $D < C_0\rho$ Cop, the equation shows that the characteristics of torque converters lead to self-induced vibration.

With torque converters having such characteristics, there is only a limited range of driving conditions that leads to torsional vibration occurring on the drive train. Therefore, vibration will not be experienced very often on vehicles equipped with a torque converter having the characteristics described above. During normal start-off, the area in which the capacity coefficient rises in accordance with speed increase is quickly passed, and vibration will be short-lived. On the other hand, if the area is passed slowly, vibration will linger. The higher the engine output torque, the worse the vibration will become. A typical example of this is when starting off in reverse on a climb.

3.3 Engine speed control

It is natural to try to control engine torque by monitoring for torsional vibration of the drive shafts. Vehicles on the market are not normally equipped with sensors for drive-shaft torsional vibration, but engine speed (angle) sensors can be used to detect the torsional vibration. Therefore, by feeding sensor signals back to a torque control system (throttle, fuel or ignition timing), vibration reduction appears to be easily achievable. On automobile engines, however, torque is generated only after a full sequence of intake, compression and expansion strokes is completed. The delay is not a considerably smaller than the vibration period. Assuming that the torsional vibration system has a damping coefficient of 0.1 and that the engine generates torque only on delayed strokes, the effect of speed feedback control in reducing speed fluctuation was calculated. The results are shown in **Fig. 7**. As clearly indicated, the phase delay for the entire system is so large that there is hardly any feedback gain for stable control. This means that performing speed feedback on internal combustion engines when torsional vibration has occurred amplifies speed fluctuation, so this method is not suitable for vibration reduction. If speed feedback is activated at low gear ratios while no active vibration reduction feedback has been programmed, vibration that is induced by external disturbance will linger. Also, if vibration continues even after the steady state is restored, it should be checked whether or not a speed feedback system has been installed.

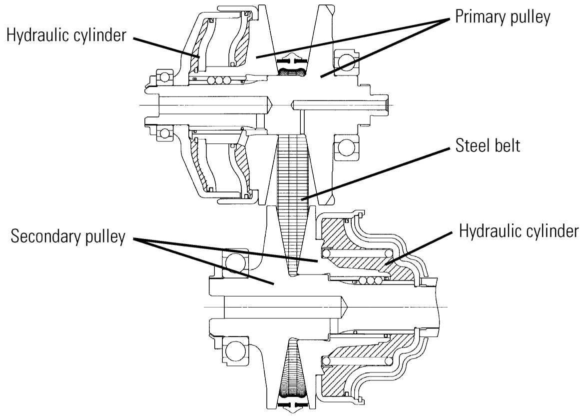

Fig. 8 Hydraulic speed variation system on CVT

3.4 Hydraulic gear ratio control system on CVT (Fig. 8)

On CVT, power is transmitted via a belt. If the cramp pressure on the secondary pulley to grab the belt is too weak, the belt and pulley will slip and the input torque cannot be transmitted any further. The minimum pulley cramp pressure required to transmit power via the belt is determined based on the input torque. The CVT controller performs pressure feedback control, including calculating the correct pulley cramp pressure based on the input. The gear ratio in the steady state is determined by the relation between the pressure of the line (secondary pressure) and the primary pressure. Normal gear ratio control is achieved by means of speed feedback using speed sensors, as no dedicated sensors are provided. Two hydraulic cylinders are used on the system: The secondary cylinder serves as a reference for the required pressure to transmit torque while the primary cylinder is designed to change pressure to achieve speed variation. Increasing the pressure will reduce the gear ratio while lowering the pressure will increase the gear ratio.

If the control system with a dual feedback loop is disturbed by external disturbance, self-induced vibration may result.

The gear ratio of CVT is determined based on the belt wrap diameters on the primary (input) and secondary (output) pulleys. The gear ratio is determined based on the ratio of primary to secondary pulley cramp

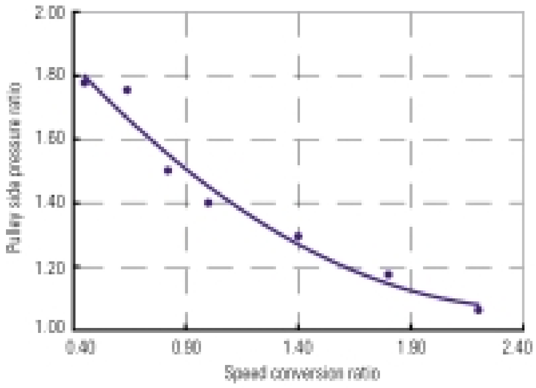

Fig. 9 Relation between gear ratio and pulley cramp pressure ratio in the steady state

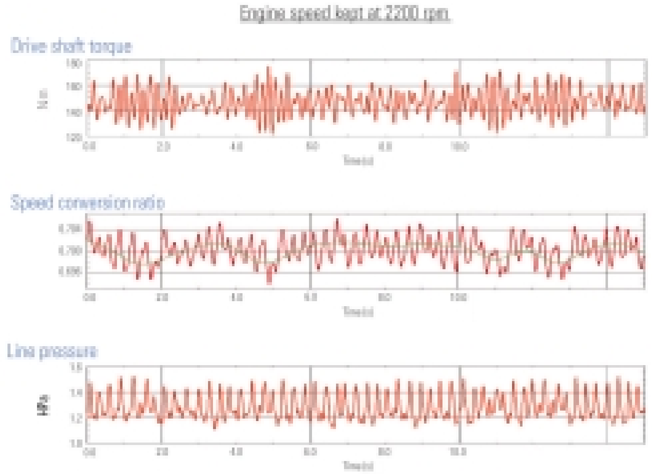

Fig. 10 Intensification and continuation of hydraulic system vibration

pressures. If the ratio changes, so does the gear ratio accordingly. **Fig. 9** shows an example of the relation between the gear ratio and the pulley cramp pressure ratio in the steady state. The primary and secondary pulley cramp pressures are dependent on the oil pressures in the primary and secondary hydraulic cylinders respectively. The relation between the oil pressure and the pulley cramp pressure can be expressed using the following equations. Within the range of self-induced vibration handled in this paper, the oil pressure and the pulley cramp pressure are in proportion to each other.

$$F_p = P_p A_p + \omega_p XF_c$$

$$F_s = P_s A_s + \omega_s XF_c + K_p \quad (4)$$

where
F_p : Primary pulley cramp pressure
F_s : Secondary pulley cramp pressure
A_p : Primary cylinder cross sectional area
A_s : Secondary cylinder cross sectional area
ω_p : Primary speed
XF_c: Centrifugal hydraulic pressure coefficient
P_p : Primary hydraulic pressure
P_s : Secondary hydraulic pressure

The converted speed can be expressed using the following equation[4].

$$\frac{di}{dt} = K_i\left(\Delta F_p / F_s\right) \quad (5)$$

where
K_i : Gear coefficient
$\Delta F_p / F_s$: Deviation from steady-state pulley cramp pressure ratio

Gear control means controlling P_p to change F_p, determined by equation (4), and thereby achieving the converted speed as shown in equation (5). This type of control is in no way stable, as the closed-loop system contains integration, as shown in equation (5), and the hydraulic system entails delayed response. If torsional vibration starts on the drive shafts due to external disturbance such as a stepped change in engine torque or load, and the responsiveness of the hydraulic feedback control is not quick enough, the following occurs: the secondary hydraulic pressure rises when there is a negative speed phase swing. while the pressure drops on a positive phase swing. This further results in the following: Where there is a pressure rise, the pulley cramp pressure increases and the gear ratio drops and the shaft driving torque drops. Where there is a pressure drop, the gear ratio increases and the torque rises. This means that the resultant gear helps to increase vibration. Unless the system including the hydraulic control system has sufficient stability margin, torsional vibration of the drive train will continue. The vibration will cease when equilibrium is lost due to change in input torque or gear ratio.

Fig. 10 shows measurements of self-induced vibration.

3.5 Gear shift

With the vehicle stationary, when the transmission is shifted from neutral into D or R, the input will consist of the moment of inertia at that time and the torque that has been absorbed by the torque converter at the idle speed. This is similar to engine torque input to the drive shaft while the input may become impulsive depending on the contribution of the moment of inertia term. This can particularly be compared with engine braking input. **Fig. 11** shows the acceleration waveform.

4. Active vibration reduction control

Earlier in this paper, factors contributing to vibration were described, which include torque converter characteristics, engine speed feedback, and CVT gear ratio control hydraulics. Vibration caused by these factors can be eliminated by selecting correct characteristics and appropriately designing the control system (applied conditions). The following paragraphs examine how to actively dampen vibration caused by torque change

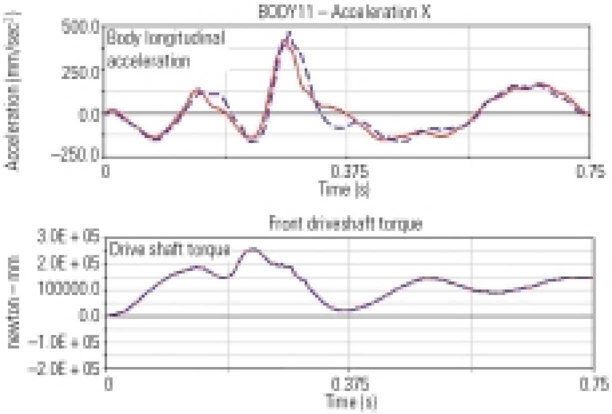

Fig. 11 Gear shift-induced vibration

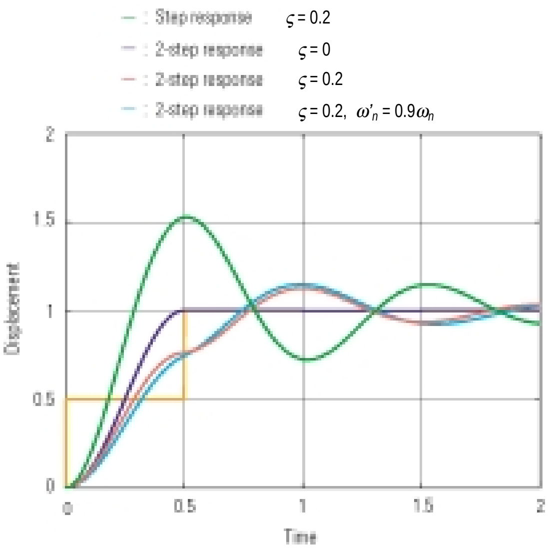

Fig. 12 Vibration reduction by antiphase torque generation and control robustness

resulting from the driver's acceleration input. From the design point of view, there are two types of active vibration reduction.

4.1 Time response waveform design

4.1.1 Accelerator filter

This method is designed to blunt the engine torque output response to the accelerator input, and is employed on electronically controlled throttles, some cable-operated throttles, and electronic fuel injection on diesels. One of the simplest designs is to achieve the target engine torque by filtering the accelerator input. Vibration reduction can also be achieved by retarding the ignition timing. The related characteristics will be described later in the section regarding the frequency-based design.

4.1.2 Canceling out vibration by generating antiphase force (two-stage torque)

Torque is applied in steps and, at a half waveform of vibration, torque with the identical waveform is applied in steps to generate an antiphase response waveform. If the system is linear, the waves offset each other and no vibration occurs. As shown in **Fig. 12**, this is intuitively easy to understand. However, to overlay an identical waveform 180˚ out of phase, it is necessary to input a wavelength identical to that of the undamped (no energy dissipation) vibration system. In reality, however, vibrations will damp and they will not overlap with each other even if staggered 180˚. Also, it is difficult to produce identical torque waveforms on the engines. While it may be possible to generate a half torque in two stages on CDI engines, it is extremely difficult on gasoline engines (except those with direct cylinder injection) to generate identical torque waveforms in two stages. Assuming that a two-stage torque waveform can be repeated, the effect of damped vibration and that of frequency shift (timing error for the generation of second-stage torque) were simulated. The results are shown overlaid in **Fig. 12**, revealing that this method is susceptible to parameter fluctuations. Also, this method is not suitable for application to random target accelerator maneuvers as future trajectory are pre-determined. In addition, while selection and memorization (max. 0.25 S) of future trajectory of accelerator maneuvers can be employed when target values are pre-determined as in mode driving, they cannot be employed for actual driving where accelerator maneuvers are unpredictable and therefore it is difficult to develop a complete algorithm.

In a report that has been published(6) on an application of this method, torque was generated slowly in two stages. This indicates the difficulty in accurately generating identical torque waveforms in two stages. In this case, rather than torque being generated in two stages, it appears that, as also described later in the section regarding the frequency-based design, this serves as a low-pass filter for the torque waveform actually produced and that this is the largest factor in torque suppression effect.

In addition, as also described later in the same section, ramp generation of torque in synchronization with vibration period also has similar effects as well as susceptibility to parameter fluctuation.

4.1.3 Active power train mounts

Active power train mounts have been used on some vehicles on the market as a means of vibration reduction, but they are designed for only a small amplitude of vibration in synchronization with the speeds in steady-state driving. The related actuators have a cutoff frequency of several dozen Hz, and their response speed is fast enough for drive shaft torsional vibration reduction. However, no actuators are yet available for practical use that can dampen transient vibration. Some of the challenges that need to be solved include the expansion of operating range, and follow-up control including the prediction of impulsive inputs. The simulated prediction performance of a virtual system is shown in **Fig. 13**.

It should be noted that contribution analysis showed that the suspension system also contributes as much vibration input as the power train. Therefore, if vibra-

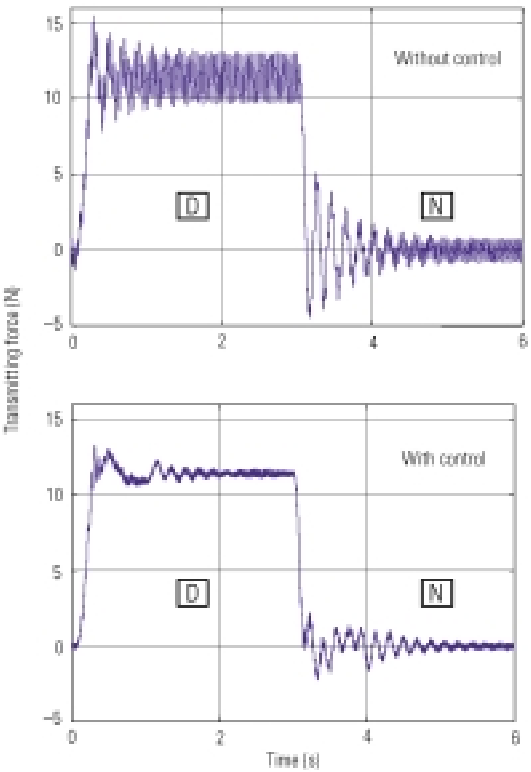

Fig. 13 Improving gear shift shock by means of mount control

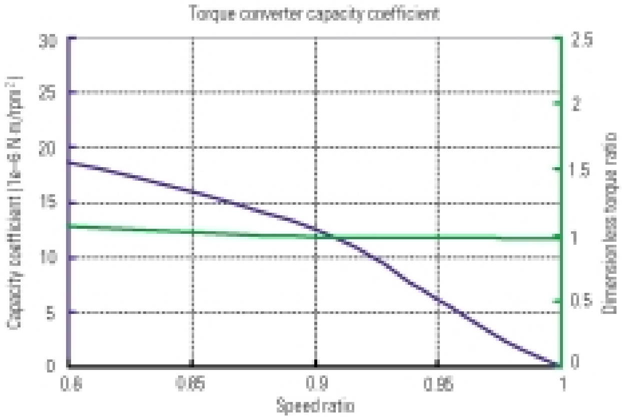

Fig. 14 Torque converter characteristics

tion via the power train can be completely dampened, this only goes halfway towards completely eliminating the entire vibration.

4.1.4 Engine torque control for added damping

It has been proposed that responsiveness be predicted using a vehicle vibration model for engine torque control feedback. This aims to enhance damping by the entire system by means of vibration speed feedback. This method can be applied even if the plant is not linear. If the plant is linear, this will be equivalent to the band-stop filter mentioned later in this paper[1].

4.2 Design of frequency response characteristics

The frequency characteristics of the vibration system show rising at the resonance frequency by the damping coefficient and dropping by 40 dB/dec. In designing a vibration reduction system, it is required to reduce the peak gain to approximately 0 dB. Potential actuators include the torque converter, damper clutch and engine torque. Potential design may include the low-pass filter, which can easily be adopted, and band-stop filter, which does not compromise responsiveness. Another possibility is to develop appropriate frequency characteristics, but this is not feasible in terms of actuator performance and robustness.

4.2.1 Torque converter lockup cutoff control

This can be achieved by reducing the peak resonance frequency for the power train. The transmission characteristics of a torque converter while the vehicle is driving can be classified as approximately a first-order delayed system having low cut-off frequencies. This method is highly effective in reducing vibration and therefore has been used for some time. The transmission characteristics can be verified based on related time response, but can also be obtained by a linear approximation of the equations of motion.

$$I_e\dot{\omega}_e = T_e - C\left(\frac{\omega_e}{\omega_t}\right)\omega_e^2$$

$$T_i = \tau\left(\frac{\omega_e}{\omega_t}\right)C\left(\frac{\omega_e}{\omega_t}\right)\omega_e^2 \qquad (6)$$

Ti : CVT input torque

With the torque converter lockup disengaged, τ will be approximately 1 while C can be linearly approximated.

Using these equations, the transfer function from T_e to T_i can be expressed as follows.

$$\frac{1}{(1+Ts)} \qquad (7)$$

This indicates a first-order delayed system. Time constant T is determined by I_e/K_c. K_c is the gradient of C.

For the torque converter indicated in **Fig. 14.** T is approximately 0.3 s at an engine speed of 1,500 rpm.

However, this method preferably should not be used as it is accompanied by higher fuel consumption (approx. 2 % max. in 10·15 mode) from the time the torque converter lockup is disengaged until it is locked up again.

As the transmission characteristics of the damper clutch are second order, the frequency characteristics show dropping by 40 dB/dec under the resonance frequency. If the cutoff frequency is well below the torsional vibration frequency of the power train, the damper clutch is effective in reducing vibration. However, during acceleration the damper clutch operates in the range of high spring constants. With the resonance frequency of approximately a dozen Hz, the damper clutch cannot serve as a low-pass filter for pow-

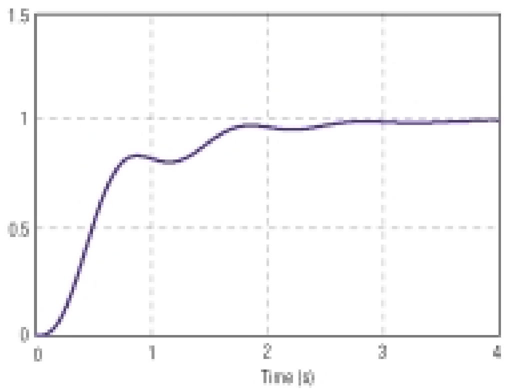

Fig. 15a The effect of low-pass filter in reducing vibration

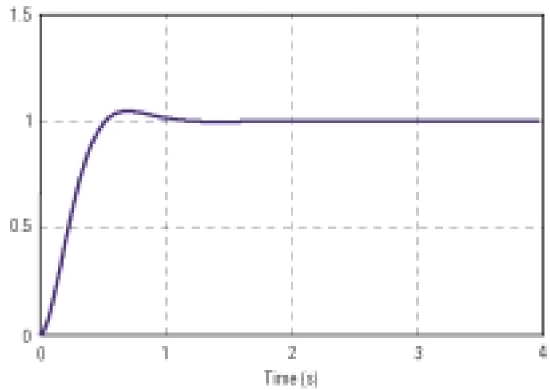

Fig. 15b The effect of band-stop filter in reducing vibration

er train torsional vibration.

4.2.2 Engine torque control

In recent years, the degree of freedom of engine torque control has grown rapidly. Electronically controlled throttles are commonly used on gasoline engines while common-rail injection is becoming the mainstream on diesel engines. On CDI diesel engines, in particular, torque control across the entire range is possible for each stroke. This ensures arbitrarily generation of torque waveform in time series, offering the maximum possible effect in reducing power train vibration. Low-pass filter characteristics can be obtained by slowly building up torque, similarly to torque converter lock up disengaged. In the following paragraphs, the concept of engine torque waveform in time series and its effect will be explained. Application to actual engines while taking into account the constraints on actuators will be described in the next section.

(1) Low-pass filter

The driver controls the engine output by means of the accelerator pedal. If the accelerator and throttle are mechanically linked, the distance that the accelerator pedal is depressed corresponds to the torque. This also holds true with electronically controlled throttles. Now, the engine output is controlled such that the engine response to the accelerator pedal movement, the requested torque in this case, is low-pass in terms of frequency response. Of course, the cutoff frequency should be selected so that torsional vibration can be dampened. With such a filter installed onto the accelerator, the response was simulated and the results were as shown in **Fig. 15a**.

The figure shows that the filter is effective in reducing vibration, but acceleration feel is somewhat compromised.

(2) Band-stop filter (notch filter)

It is possible to design a filter that only dampens resonance frequency without compromising acceleration feel. The transfer function consists of the drive shaft torsional resonance system as the numerator and the transfer function of the new system as the denominator. This should ensure appropriate damping. Simulated results of this system are shown in **Fig. 15b**.

In the previous section, two-staged torque buildup was explained. The characteristics of this method can now be clearly understood when looked at in terms of frequency. The amplitude is deeply notched at the resonance frequency. If low-damped vibration has that frequency, vibration reduction can be nearly perfect. This notch, however, is narrow and, once outside the notch, vibration cannot be damped sufficiently. This is similar to what we observed in the section regarding the time response waveform design. Waveforms with similar characteristics (notch filter) can be observed in many other occasions including ramp buildup and four-stage buildup.

5. Applying active torque control to actual engines

Now that the target characteristics have been established, the following paragraphs will focus on how accurately the engine torque can be controlled.

5.1 Control range and effect

5.1.1 Constraints of control force

With internal combustion engines, it is not possible to control negative torque. This makes it difficult to control deceleration, and also acceleration, particularly with respect to the algorithm designed to improve responsiveness.

Torque control by means of ignition timing can only achieve a reduction of approximately 40 % due to combustion stability requirements. Needless to say, it cannot increase the torque more than the throttle valve does. However, the method offers great possibility for shock reduction if used properly. **Fig. 16** shows torque control by means of ignition timing that has been applied to vibration reduction.

5.1.2 Time resolution constraints

Torque is generated by the engine continuously while torque control is possible only once per stroke. As shown in **Fig. 17**, torque has a pulse-like waveform, consisting of combustion pressure and moment of inertia, combustion pressure is only controllable. Performing control primarily alters the maximum value of the combustion pressure. This makes it difficult to analysis & design control in frequency domain.

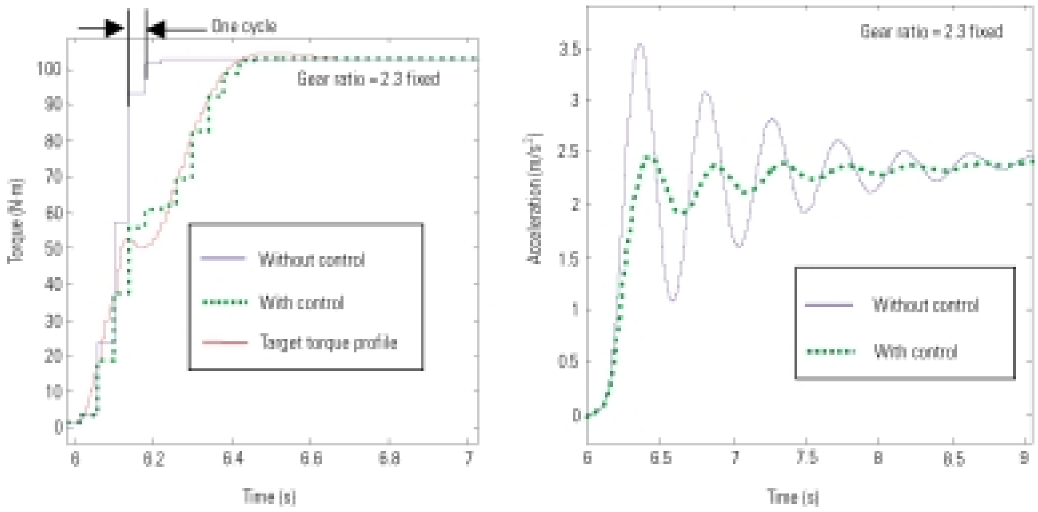

Fig. 16　Effect of ignition timing control

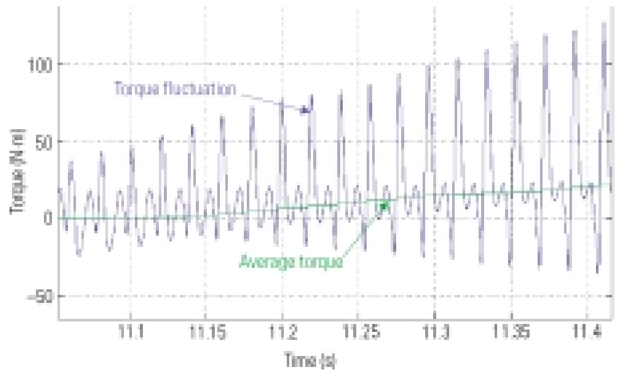

Fig. 17　Engine torque waveform

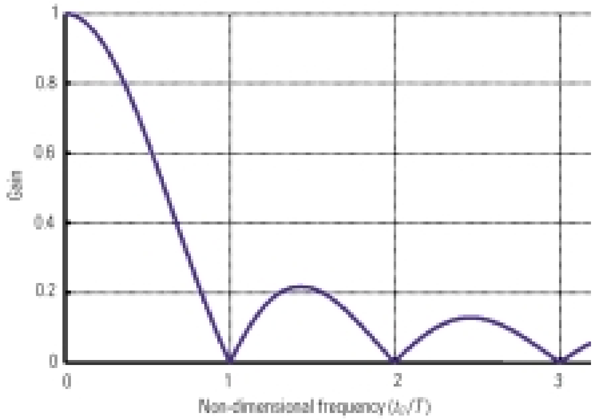

Fig. 18　Frequency characteristics by discrete torque generation (approximation)

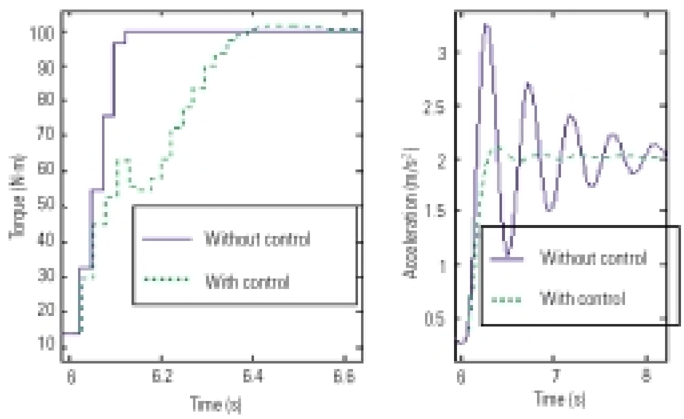

Fig. 19　The effect of time-based control

Therefore, a zero-order hold waveform with the same area is now considered. As shown in **Fig. 18**, the frequency characteristics indicate a precipitation to zero at ω0 (near sample frequency). Similar frequency characteristics can be obtained by approximating torque using a triangular waveform, which is more similar than a zero-order hold waveform, to the engine torque waveform. However, when this method is used, the notch in the sample frequency moves towards second harmonics. Band-stop filters will not achieve the expected improvement in performance responsiveness if the engine speed is relatively lower than the resonance frequency while low-pass filters will be affected only slightly in this respect. **Fig. 19** shows the control effect in the time domain.

5.1.3　Intake system constraints

Gasoline engines have constraints in the throttle and the intake system. The intake system is a first-order delayed system as the difference in mass between the volume of air passing the throttle and the air sent to the cylinders accumulates there. A 1.5-L 4-cylinder engine with an intake-pipe volume of approximately 3 L has a time constant of approximately 0.17 s and a cutoff frequency of approximately 0.93 Hz at 1,500 rpm. The corresponding figures at 2,000 rpm are 0.086 s and 1.9 Hz respectively. At these engine speeds and frequencies, low-pass filters will not be effective in reducing drive shaft torsional vibration.

The first-order delay mentioned earlier relates to the volume of air passing the throttle, and it is not assumed

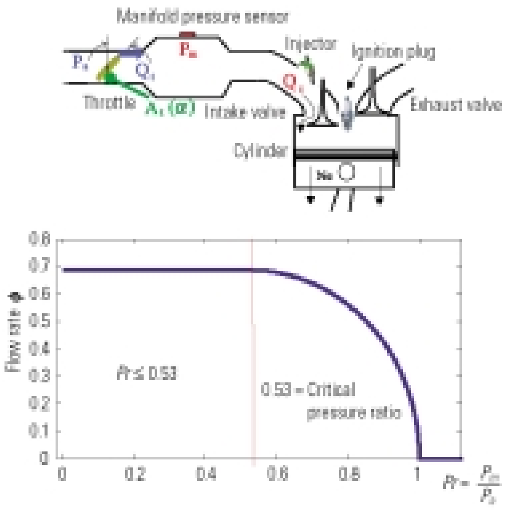

Fig. 20 **Intake system and characteristics function**

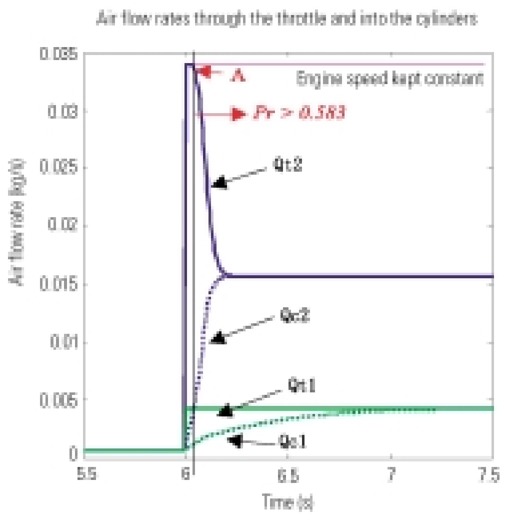

Fig. 21 **Impact of rush of air**

that this volume will change depending on the pressure in the intake piping. When the pressure in the intake piping is relatively low, opening the throttle causes the volume of air passing the throttle to increase rapidly before returning to the steady state. This initial rush of air enhances the responsiveness of the intake air system, bringing the time constant lower than the previously mentioned level. The system is no longer a first-order delayed system relative to the throttle opening degree. Therefore, attention must be paid to a possible increase in the cutoff frequency or gain increase in the range above the cutoff frequency.

Fig. 20 shows the intake system and characteristics function ϕ while **Fig. 21** shows the increase in gain due to the rush of air.

5.2 Compensating filters with throttle control

5.2.1 Low-pass filter type compensator

At a drive shaft torsional resonance frequency of ωv, the amplitude will increase by approximately 15 dB. A

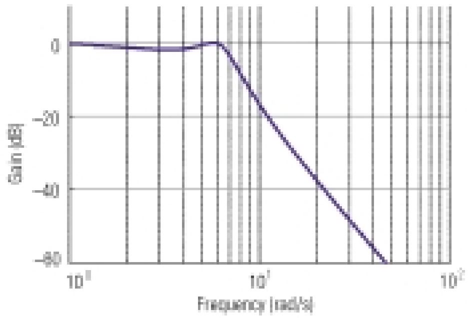

Fig. 22 **Frequency characteristics of compensating low-pass filter**

filter capable of damping as much as 12 dB is designed, which is achieved by setting the cutoff frequency ωc at 1/4 ωv. The filter has a time constant of 0.28 s at 2.3 Hz resonance and 0.13 s at 5 Hz resonance. The effect of the time constant for the intake system should also be taken into account. As the torque control being studied is aimed at vibration reduction, the input and output of the filter take the form of torque. They are not the throttle opening, but the equivalent volume of intake air per stroke. To the state of critical flow, the throttle opening, which is calculated backwards from the steady-state air volume passing the throttle, can be used. With larger opening degree, the error became greater. To control the entire range with such characteristics, a throttle compensator needs to be installed after the compensating filter. **Fig. 22** shows the frequency characteristics with a first-order low-pass filter while **Fig. 24** shows the frequency characteristics of zero-order hold approximation of the engine torque. They are almost identical to each other below the resonance frequency. Discrete engine torque does not have any significant negative impact due to the characteristics of a low-pass filter, so special design considerations in this respect will not be necessary.

5.2.2 Band-stop filter type compensation

As mentioned earlier, there is a range of filters, but compensators that have low sensitivity (or robustness) to various conditions can be expressed as follows.

$$C(s) = \frac{s^2 + 2\varsigma\omega_n s + \omega_n^2}{s^2 + 2\varsigma'\omega_n s + \omega_n^2} \qquad (8)$$

ω_n is the same as for torsional vibration frequency. The new damping coefficient should be set at approximately 0.7. Robustness can be enhanced by increasing the damping coefficient. Conversion of compensator output into throttle opening is the same as with a low-pass filter while accuracy is required depending on the tracking performance of the waveform. **Fig. 23** shows the compensated frequency characteristics of the vibration system. The vibration reduction performance of band-stop filters can be heavily affected by discrete engine torque, as mentioned earlier. If continuous, the vibration can be damped completely. However, as the ratio of engine speed to resonance frequency drops,

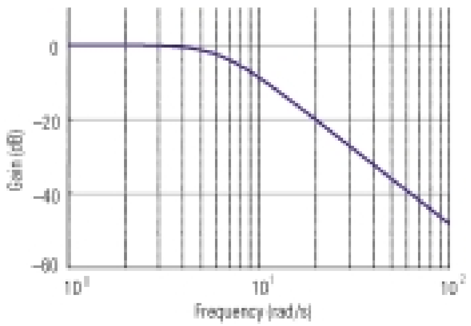

Fig. 23 Frequency characteristics using a compensating band-stop filter

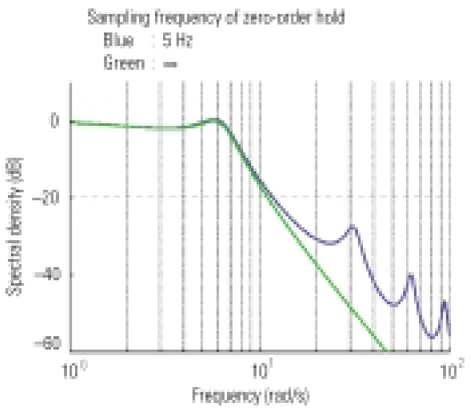

Fig. 24 Change in frequency characteristics due to discrete torque (low-pass)

deviation from ideal torque grows considerably, reducing the vibration reduction efficiency. Vibration reduction efficiency drops even when the torque generating frequency (two times the speed on 4-cylinder engines) is ten times the resonance frequency. When the torque generating frequency is five times the resonance frequency, vibration will remain. This is shown in **Fig. 25**. Five times the resonance frequency of 5 Hz corresponds to an engine speed of 1,500 rpm.

5.2.3 Band-stop filter using practical throttle control

We have looked at discrete torque generated on reciprocating internal combustion engines, the characteristics of the intake system and torque generation of gasoline engines, and their impacts on vibration reduction. We now look at practical throttle control.

Under the conditions of a small throttle opening and an intake pipe pressure at the critical air flow, it is possible to control the air flow rate in approximate proportion to the throttle opening. In other words, even if torque is used as throttle opening through a certain conversion calculation, a band-stop filter can be realized. This also has some control effect. Wherever this brings the intake pipe pressure to high levels, the throttle opening can be determined on a real-time basis in accordance with the intake pipe pressure using an algorithm while taking into account the characteristics function ϕ and the area of the throttle opening.

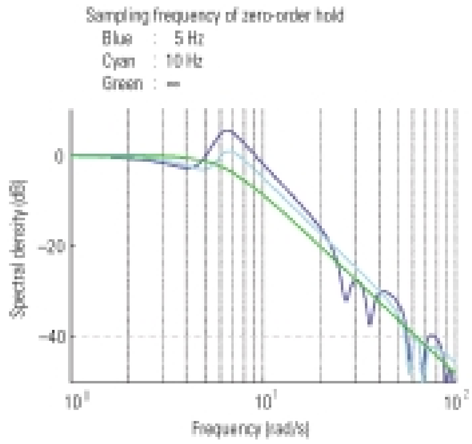

Fig. 25 Change in frequency characteristics due to discrete torque (band-stop)

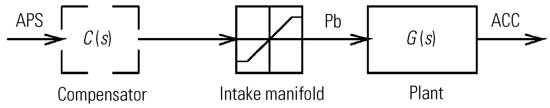

Fig. 26 Practical throttle control and band-stop filter

Also, Amano et al.[7] presented a relatively simple algorithm to perform control up to the full-open position. Under the algorithm, the compensator can be expressed using equation (8) while the compensator constant is variable in the area above the critical flow rate. Vibration reduction can be obtained without having to perform complex nonlinear operations. **Fig. 26** shows the control system while **Fig. 27** shows the vibration reduction effect.

6. Summary

Drive train torsional vibration is caused by the automobile power train, which consists of the engine and transmission, both having a relatively large moment of inertia, coupled onto the shaft with a relatively low rigidity. With this arrangement, a sudden change in torque (or external disturbance) can cause annoyance to the occupants. While various passive measures have been taken to eliminate this using power transmission elements such as power train mounts and clutches, active control of vibration sources is most effective, as described in this paper. Engine torque control can be easily achievable on ordinary vehicles on the market. Therefore, it appears that in future the primary damping will be provided by engine torque control while the power transmission elements will be left with reasonable degrees of freedom to deal with other constraints.

7. Acknowledgment

Information regarding the examples of practical control systems was provided by the Hirai Laboratory of Nagoya Institute of Technology. Drawings of discrete

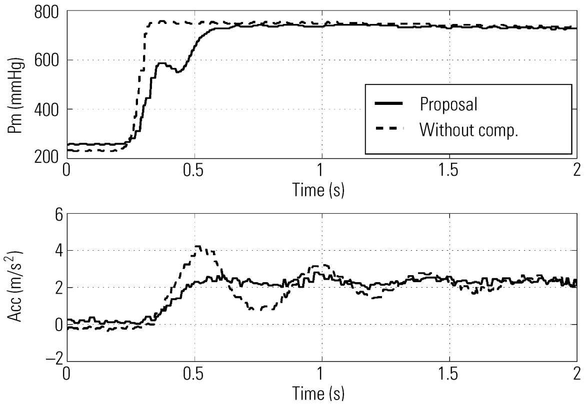

Fig. 27 The effect of band-stop filter using practical throttle control

system frequency characteristics were produced by Mr. Yamaura of Mitsubishi Automotive Engineering. We would like to express our appreciation to those who extended cooperation.

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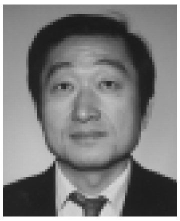
Kazuhide TOGAI


Tadashi TAKEUCHI

NEW TECHNOLOGIES

Introduction of Heat Management Analysis Method Using One-Dimensional Simulation

Masahiko KUBO* Kentaro SHII*

Abstract

Various methods have recently been introduced for investigating the engine cooling control and its effects on fuel efficiency. Thermal fluid analysis by one-dimensional simulation is an effective research and development tool for studies on the control of the entire cooling system and optimization of piping. This paper introduces examples of calculations in the one-dimensional thermal fluid analysis and a method for forecasting the coolant temperature during the mode drive and calculating the fuel efficiency by employing one-dimensional thermal fluid analysis software and the general numerical analysis tool for co-simulation.

Key words: *ATF Warmer, Electric Water Pump, Heat Management, Low Fuel Consumption, Simulation*

1. Foreword

The engine cooling control affects the improvement of combustion and the reduction of friction, and its importance in fuel efficiency has increased with the rising awareness of the environment in recent years. STAR-CD, SCRYU/Tetra and other three-dimensional computational fluid dynamics (CFD) tools are commonly used for studying the flow of fluid inside engines. While they enable detailed analyses, the analysis range and conditions are limited due to the modeling and calculation time, and there are other non-negligible problems in practical applications.

On the other hand, while one-dimensional thermal fluid analysis does not provide detailed fluid flow analysis inside a water jacket, it enables the entire cooling system control to be studied and the piping to be optimized. It also facilitates transitional calculations of the mode drive, which are difficult with three-dimensional analysis.

We are presently studying optimization of the cooling system using the one-dimensional thermal fluid analysis software “Flowmaster2” (**Fig. 1**) and the coolant control method that improves the fuel efficiency by linking with the fuel efficiency calculation model using the general numerical analysis tool (MATLAB/Simulink). This paper introduces part of the study.

Flowmaster2 can calculate the flow and pressure pulses of engine oil and fuel in addition to the cooling system, and widespread utilization is expected since it is highly adaptable.

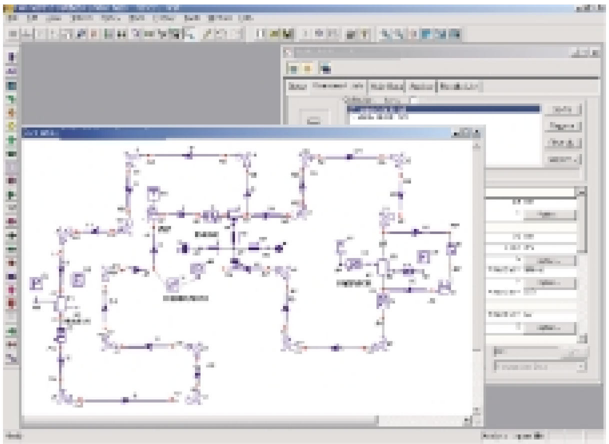

Fig 1 Flowmaster2 GUI

2. Calculation examples

(1) Verification of calculations precision

When first using the software, we verified the consistency of the coolant flow with the actual vehicle data. We selected the cooling system that has a radiator, heater and Automatic Transmission Fluid (ATF) Warmer as the heat exchangers in the calculation model (**Fig. 2**) and compared the flow. The error was 2 to 10 % and thus the calculation precision is acceptable (**Fig. 3**).

(2) Application to heat management

The main theme of heat management is how to effectively utilize the heat generated by the engine. The method by which friction is reduced by warming the ATF earlier utilizing the coolant at warm-up has been commonly adopted in recent years. This heat exchanger that uses the coolant and the engine oil is called the ATF Warmer.

We looked for the optimal piping that could secure the heater flow because adding the ATF Warmer to the cooling system decreases the coolant flow to the heater. We assumed a layout that could be installed in actual vehicle and calculated two patterns, one connected in series with the heater piping and the other parallel to

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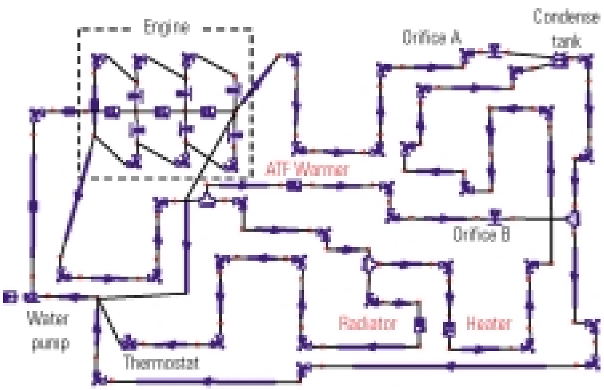

Fig. 2 Calculation model

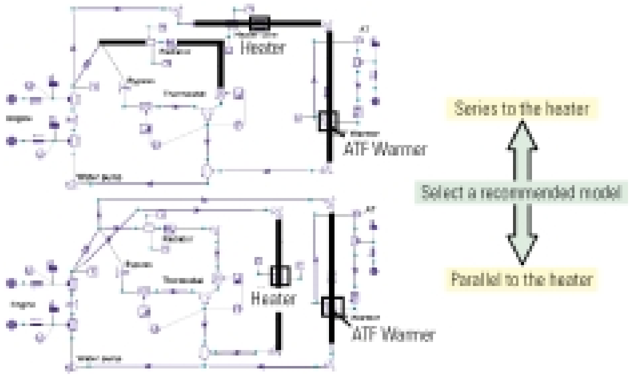

Fig. 4 Cooling system model

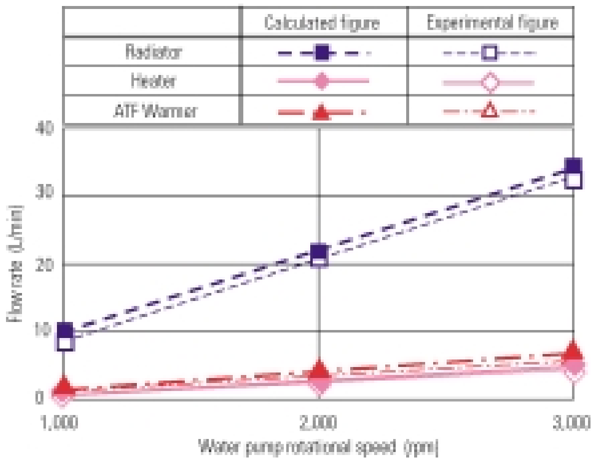

Fig. 3 Precision of Flowmaster2

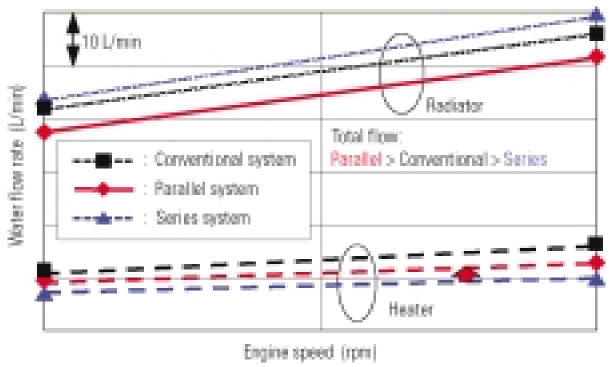

Fig. 5 Calculation result of flow rate

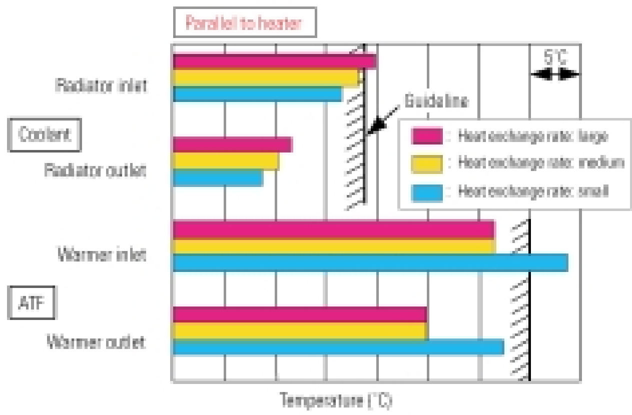

Fig. 6 Calculation result of coolant and ATF temperatures

the heater piping (**Fig. 4**).

We discovered that the parallel connection to the heater piping performs better in securing the flow in the test vehicle (**Fig. 5**).

It is also important to optimally control the temperature of the engine and the ATF after warm-up has completed. Cooling the ATF with the ATF Warmer raises the coolant temperature by heat exchange and it approaches the limit temperatures for the coolant and the engine. Reducing the cooling capability of the ATF lowers the coolant temperature but the ATF temperature rises and approaches the ATF limit.

We evaluated three types of ATF Warmers with different heat exchange ratios (small, medium and large) with the aforesaid piping by simulation analysis and discovered that the “medium” specification of the heat exchange ratio satisfies both guidelines described above (**Fig. 6**).

The results of this study were applied to the newly launched GRANDIS at the initial review.

3. Calculation of fuel efficiency with electric water pump

The most common type of water pump that circulates the coolant is driven by a belt using the engine power. In some situations it works inefficiently or overcools since the flow is not affected by the engine load but instead is proportional to the engine speed. If we use an electric water pump that can freely set the flow as needed, it would minimize the work involved and improve the efficiency. Electric water pumps have been proposed before, but there has been no actual production other than for certain models due to the balance between cost and performance. We linked the

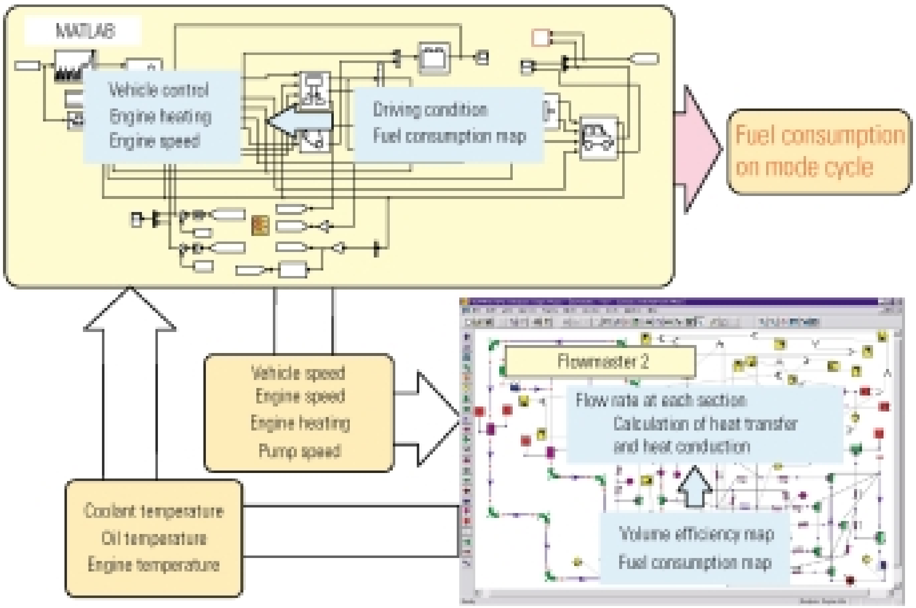

Fig. 7　Calculation procedure

Flowmaster2 to the fuel consumption calculation model MMC has developed using the MATLAB/Simulink, and minutely verified on the effect of the reduction of friction by optimizing the engine liner temperature and other feasibilities of better fuel efficiency.

(1) Calculation model

We calculated the fuel efficiency of the new COLT for Europe in the cold-start EU mode cycle.

Flowmaster2 models the inside of the engine room and MATLAB/Simulink conducts the vehicle control and fuel consumption calculation (**Fig. 7**). The fluids used in Flowmaster2 comprise air that is a running wind, combustion gas, coolant, and engine oil (**Fig. 8**).

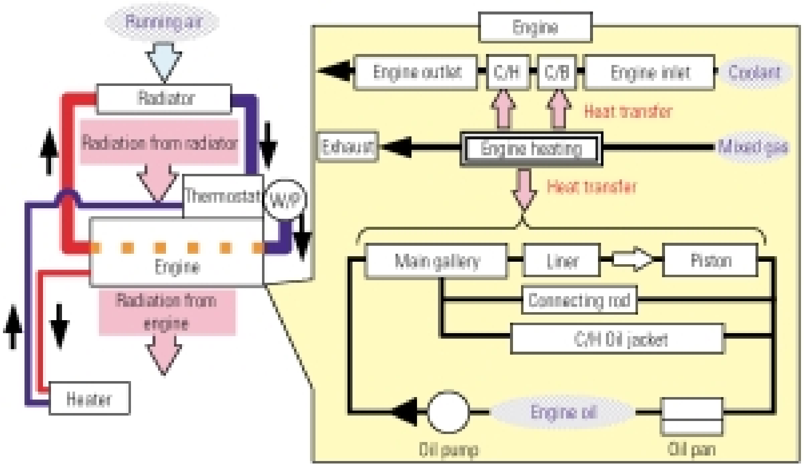

Fig. 8　Engine calculation model

(2) Calculation method

The fuel consumption rate *FC* was obtained as a function of the engine speed *Ne*, indicated mean effective pressure *Pi*, coolant temperature T_{water} and engine oil temperature T_{oil}.

$$FC = f\,(Ne, Pi, T_{water}, T_{oil}) \qquad (1)$$

The indicated mean effective pressure is calculated with consideration given to the driving loss of the belt-driven water pump and the alternator load generated by the electric water pump.

The heat transfer coefficient was obtained from the Nusselt number (*Nu*), dimensionless parameter (equations (2) – (4)), in the equations of convection heat transfer. The equations were derived from the results of bench tests (**Fig. 9**).

Heat transfer to the cylinder walls

$$Nu = a_1\,Re^{b1}\,Pr^{c1} \qquad (2)$$

Heat transfer to the jacket

Natural convection: $Nu = a_2\,Re^{b2}\,Gr^{c2}$ (3)

Forced convection: $Nu = a_3\,Re^{b3}\,Pr^{c3}$ (4)

where

Nu : Nusselt number
Re : Reynolds number
Rr : Prandtl number
Gr : Grashof number
a_n, b_n, c_n: Coefficient (n = 1 to 3)

(3) Control content

The electric water pump is controlled by the deviation between the actual water temperature and the target water temperature and the vehicle deceleration con-

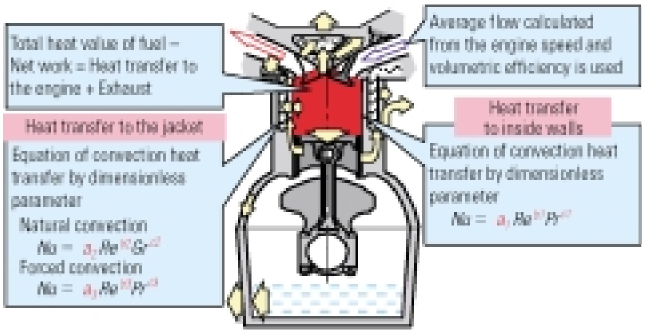

Fig. 9 Heat transfer calculation model

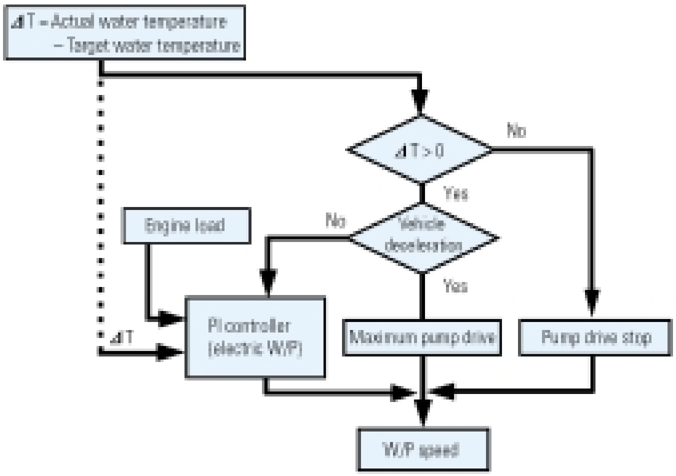

Fig. 10 Electric W/P control method

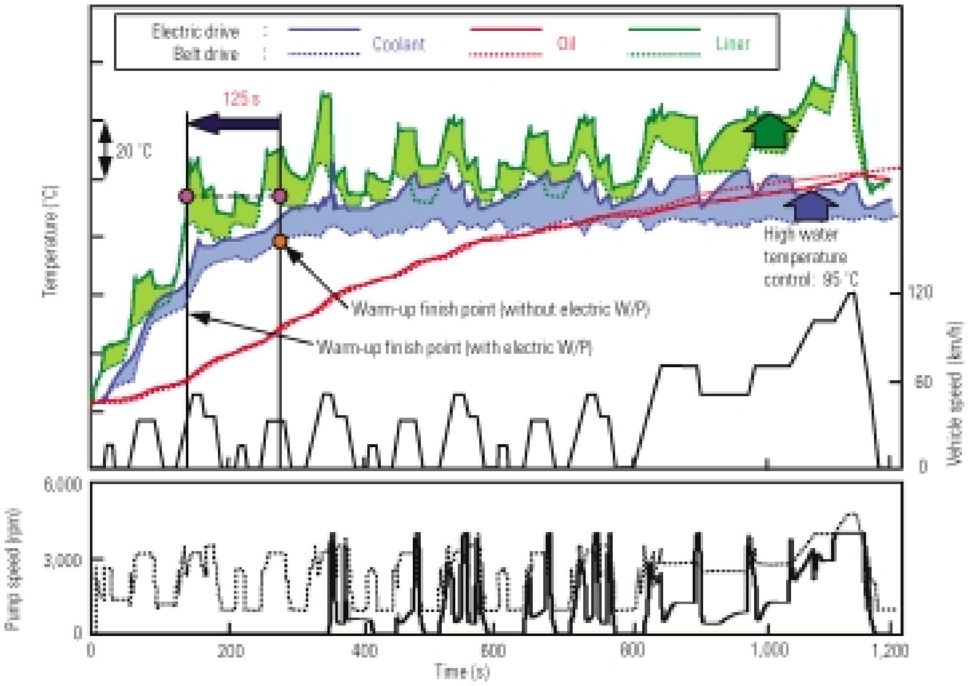

Fig. 11 Calculation result of EU mode cycle

dition (**Fig. 10**).

We used the same thermostat and thus the valve-opening characteristics are the same, but the flow control by the electric water pump regulates the coolant temperature regardless of the valve-opening characteristics.

(4) Calculation results

We were able to shorten the warm-up finish time by 125 seconds in the EU mode by adopting the electric water pump and also improve the coolant temperature after completion of warming by an average of 13 ˚C in the new COLT for Europe. The loss caused by the electric water pump was also reduced significantly due to minimum necessary driving during the mode cycle (**Fig. 11**).

About 2 % improvement of the fuel efficiency was achieved. The effect of the better fuel efficiency by the reduction of the water pump driving loss is small at 0.1 %, but it improved by about 0.6 % by stopping the water pump drive before the warm-up finishes (**Fig. 12**).

4. Summary

One-dimensional and three-dimensional analyses have advantages and disadvantages. There is another method for linking the advantages of both analyses, where we can make calculations for the piping in one-dimensional analyses model (Flowmaster2) and for the jacket inside the engine in three-dimensional analyses model (STAR-CD or SCRYU/Tetra) (**Fig. 13**).

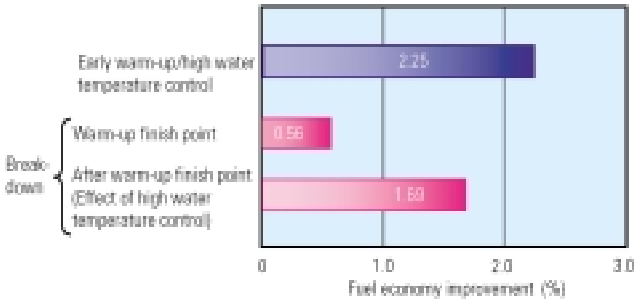

Fig. 12   Increased ratio of fuel consumption

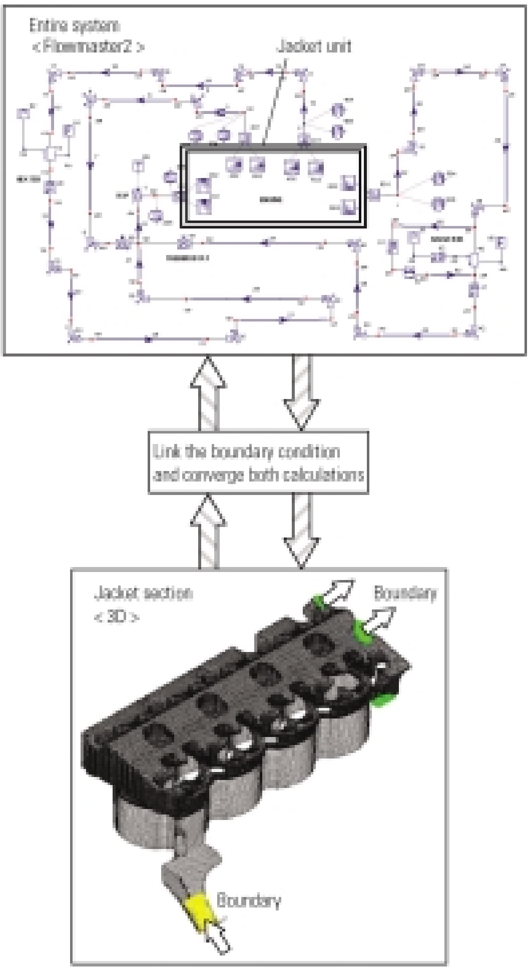

Fig. 13   1D-3D co-simulation

Linked calculations of one dimension and three dimensions in the mode drive are extremely difficult at present since the three-dimensional analysis takes a considerably long time for transition calculations.

5. Postscript

We will build further simulation technologies for heat management, apply the study results and improvements learned from simulations to products and introduce them to the market. We will also contribute to environmental protection through better fuel efficiency and low emission.

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Kentaro SHII

Prediction Technique for Road Noise

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Takashi SHIBATA** Toshihiko SUGAHARA**

Abstract

As input mechanism and transfer path of road noise were extremely complicated and input force from road surface to tire was difficult to identify experimentally, road noise was difficult to estimate quantitatively. Due to estimate the road noise quantitatively and qualitatively, therefore, a new function (called equivalent road roughness) for input force is defined. Then, a suspension vibration and interior car noise are estimated by using the equivalent road roughness, a computer-aided engineering (CAE) model (for the tires and suspension), and test data (for the body). Finally, validity of equivalent road roughness is verified.

Key Words: *CAE, Road Noise, Equivalent Road Roughness*

1. Introduction

In recent years, importance of vehicle comfort (for example vibration and noise) has been increasing. In addition, as development cycles have been significantly shortened, to ascertain the vehicles attributes and to consider proposed measures is needed at an early stage in the development process. Quantitative and qualitative prediction technique of road noise at the early development stage when suspension specifications are selected is particularly crucial.

To predict road noise, input force from the road surface is needed to identify accurately. However, as road noise is typically generated by the random input from the road surface, when the numerical simulations is operated, application of the input force is difficult. In the past, many techniques that experimentally identifying the input force to an axle shaft were proposed[(1) – (3)]. However, these techniques have two problems: First, input force depends on the suspension characteristics. Secondly, condition of the identification testing is complex. For these reasons, the input force is not ideal for application at the early stage when suspension specifications are selected. As a solution, a new function, equivalent road roughness, is defined. Equivalent road roughness is the function that is relatively easy to identify and is scarcely influenced the suspension characteristics; it depends mainly on the tire-tread rigidity and road surface roughness. Suspension vibration and interior car noise is predicted by using the identified input force, and validity of equivalent road roughness is verified. Details are given in this paper.

2. Identification of equivalent road roughness

2.1 Identification technique

The equivalent road roughness was identified for a vehicle with semi-trailing-arm suspension and 195/60R15 tire (**Fig. 1**). The measurement point used for the identification was the point 'P' in **Fig. 1**.

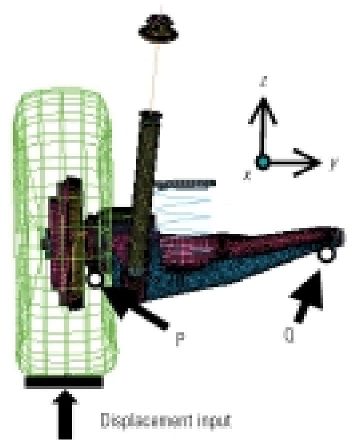

Fig. 1 Semi-trailing-arm suspension

Measurement point P's vibration acceleration $\{v_x\ v_y\ v_z\}^p$ is determined by the product of (a) the input force from the road surface to the tire contact patch area and (b) the vibration transmissibility from the tire contact patch area to measurement point P. (For details of the development of the formula, refer to Shibata[(4)]. Using the frequency function of displacement inputs from the road surface $\{D_x\ D_y\ D_z\}$, the vibration acceleration of the measurement point P is expressed as follows:

$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix}^p = \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix} \begin{pmatrix} D_x \\ D_y \\ D_z \end{pmatrix} \quad (1)$$

$\begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix}$ is the vibration transmissibility matrix from the tire contact patch area to point P when the

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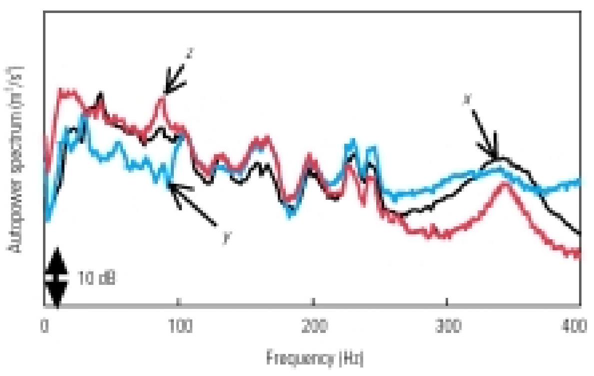

Fig. 2 Autopower spectrum

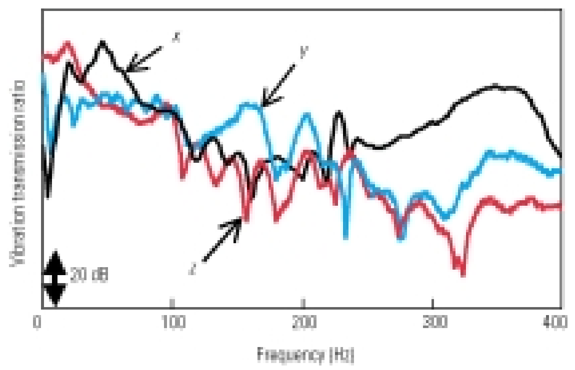

Fig. 3 Vibration transmission ratio

entire tire contact patch area is uniformly excited.

Using equation (1), the vibration cross-spectrum matrix at the measurement point P is expressed as follows:

$$\begin{pmatrix} v_x^p v_x^{p*} & v_x^p v_y^{p*} & v_x^p v_z^{p*} \\ v_y^p v_x^{p*} & v_y^p v_y^{p*} & v_y^p v_z^{p*} \\ v_z^p v_x^{p*} & v_z^p v_y^{p*} & v_z^p v_z^{p*} \end{pmatrix} = \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix} \begin{pmatrix} D_x D_x^* & 0 & 0 \\ 0 & D_y D_y^* & 0 \\ 0 & 0 & D_z D_z^* \end{pmatrix} \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix}^* \quad (2)$$

Here the direction components of inputs from the road surface are supposed to have correlation absence to each other. For example, then, $D_x D_y^* = 0$.

The left-hand side of equation (2) is a cross-spectrum matrix that can be measured by actual driving testing.

Further, $\begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix}$ is a vibration transmissibility matrix that can be measured by entire tire contact patch area excitation testing.

So the left-hand side of equation (3)

$$\begin{pmatrix} D_x D_x^* & 0 & 0 \\ 0 & D_y D_y^* & 0 \\ 0 & 0 & D_z D_z^* \end{pmatrix} = \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix}^{-1^*} \begin{pmatrix} v_x^p v_x^{p*} & v_x^p v_y^{p*} & v_x^p v_z^{p*} \\ v_y^p v_x^{p*} & v_y^p v_y^{p*} & v_y^p v_z^{p*} \\ v_z^p v_x^{p*} & v_z^p v_y^{p*} & v_z^p v_z^{p*} \end{pmatrix} \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix}^{-1} \quad (3)$$

Which is transformed the equation (2), can be identified using measurement data. Ultimately, $\sqrt{D_x D_x^*}$, $\sqrt{D_y D_y^*}$, and $\sqrt{D_z D_z^*}$ were defined as the equivalent road roughness in each direction.

2.2 Identification results and verification

The acceleration autopower spectrum for driving at a speed of 50 km/h is shown in **Fig. 2**. The vibration transmissibility from the tire contact patch are to point P when the vehicle is stationary and the entire tire contact patch area is uniformly excited is shown in **Fig. 3**. The equivalent road roughness identified based on these data is shown in **Fig. 4**. This figure indicates that the equivalent road roughness of the z-axis direction level is higher than the others and that its contribution to road noise is concomitantly high.

For verification of the results of identification, vibration data for the point 'Q' in **Fig. 1** were calculated using equation (4), which applies the identified equivalent road roughness and the vibration transmissibility to point Q.

$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix}^Q = \begin{pmatrix} H_{xx} & H_{xy} & H_{xz} \\ H_{yx} & H_{yy} & H_{yz} \\ H_{zx} & H_{zy} & H_{zz} \end{pmatrix} \begin{pmatrix} \sqrt{D_x D_x^*} \\ \sqrt{D_y D_y^*} \\ \sqrt{D_z D_z^*} \end{pmatrix} \quad (4)$$

The results are shown in **Fig. 5**. This figure indicates that the measurement data and calculation data agreed with ample accuracy.

2.3 Study with different suspension system

In the introduction, equivalent road roughness is scarcely depend on suspension characteristic and depend on the tire tread rigidity was stated. To verify it, the equivalent road roughness was identified with multi-link suspension shown in **Fig. 6**. The suspension system and bearing type were different from those mentioned in part 2.2 of this paper, but the tire type was the same. The driving conditions were the same as those mentioned in part 2.2. The measurement point was the point 'R' in **Fig. 6**.

The equivalent road roughness identified with the multi-link suspension and the semi-trailing-arm suspension are compared in **Fig. 7**. This figure indicates that the identified equivalent road roughness have slight differences. However, vertical-direction equivalent road roughness, which makes the highest contribution to road noise, had approximately the same level as the

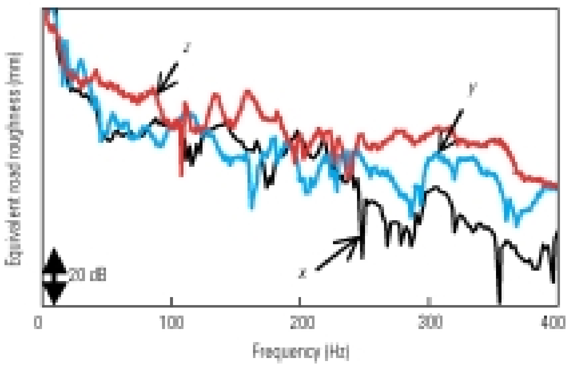

Fig. 4 Equivalent road roughness

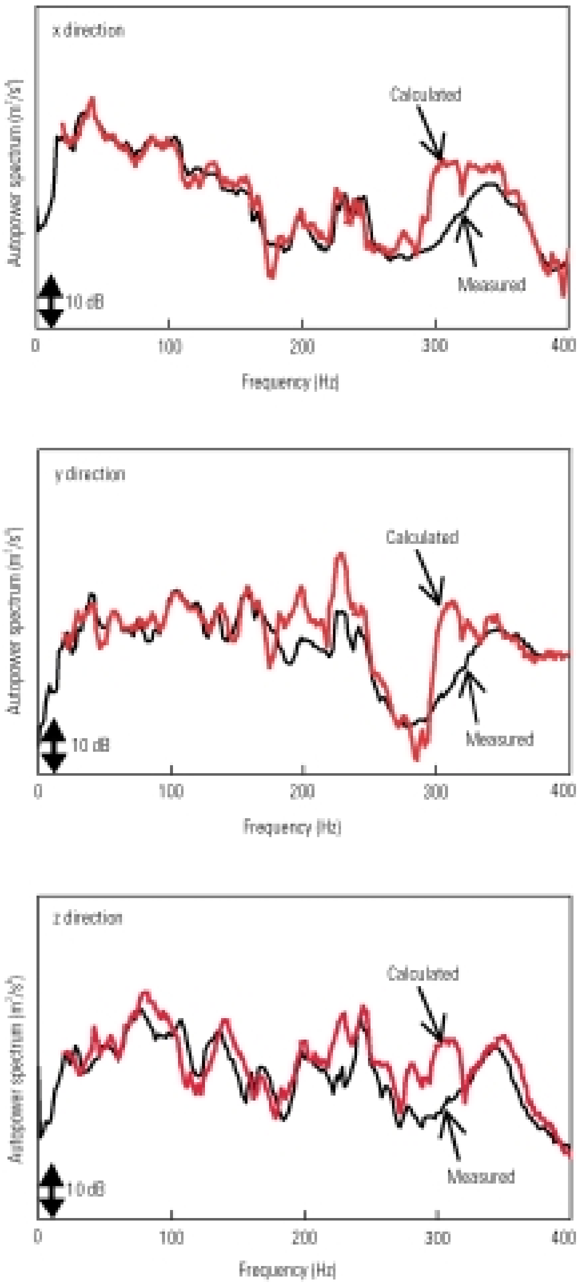

Fig. 5 Comparison of the measurement and calculation

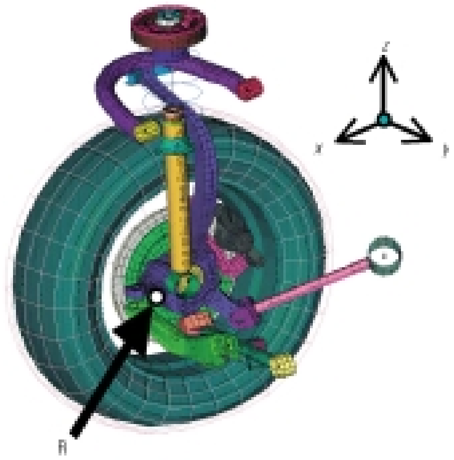

Fig. 6 Multi-link suspension

semi-trailing-arm suspension. Consequently, these results indicate that the proposed equivalent road roughness is adequately useful at the development stage when suspension specifications are selected.

3. Numerical simulation

Numerical simulation was performed using the identified equivalent road roughness on the assumption of actual suspension selection in vehicle development.

3.1 Analysis conditions

It was assumed that multi-link suspension was adopted instead of semi-trailing-arm suspension, and suspension vibration and interior car noise were calculated in accordance with the conditions shown in **Table 1**.

Finite-element model was applied to the tire and suspension. In this model, the tire deformation and suspension geometry were taken into account the application of vehicle weight. And the vibration transmissibility from tire contact patch area to the suspension and body connecting point is calculated. On the body side, the transfer function between the each suspension connecting point, the excitation-point inertance of the suspension and body connecting point and the acoustic transfer function from suspension and body connecting point to the interior car noise measurement point is measured by the hammering excitation testing with the actual vehicle. Based on these data, the suspension vibration and interior car noise were predicted using the FRF based sub-structuring method.

3.2 Results of analysis

Measurement and calculation data of the vibration and interior car noise are shown in **Figs. 8** and **9**. Vibration measurement point is lower arm and body connecting point. Each figure indicates that the suspension vibration and interior car noise data were calculated with extremely high accuracy.

From these results, the proposed equivalent road roughness is useful in CAE numerical simulations per-

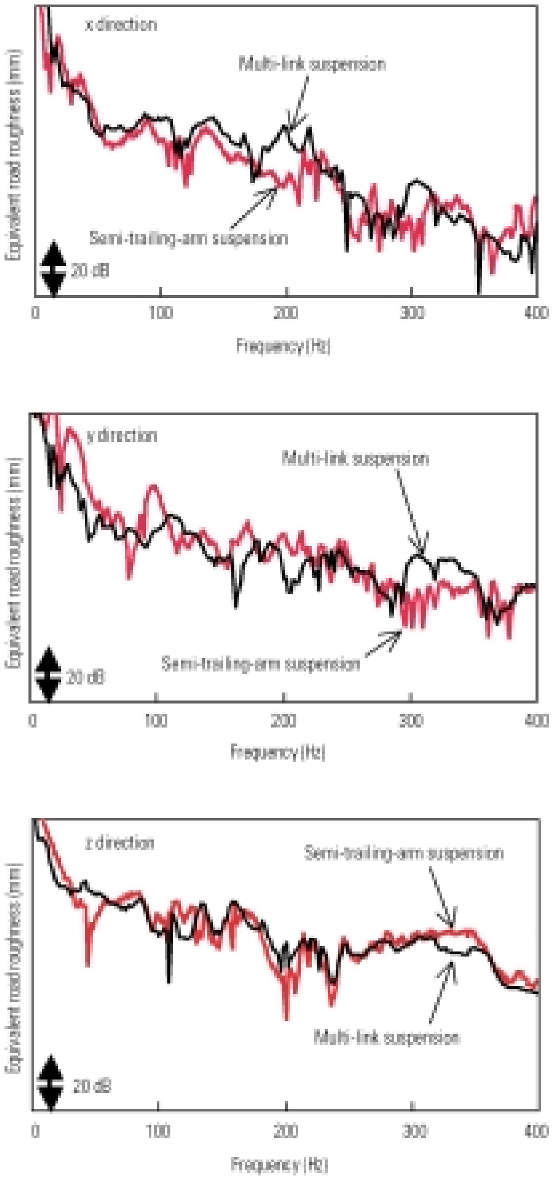

Fig. 7 Comparison of the equivalent road roughness for two suspension systems

Table 1 Analysis conditions

Analysis method	FRF based sub structuring method
Equivalent road roughness	Identified for semi-trailing-arm suspension
Tire	FEM taking tire deformation caused by vehicle weight into account
Suspension	FEM of multi-link suspension
Body	Transfer function measured from actual vehicle measurement

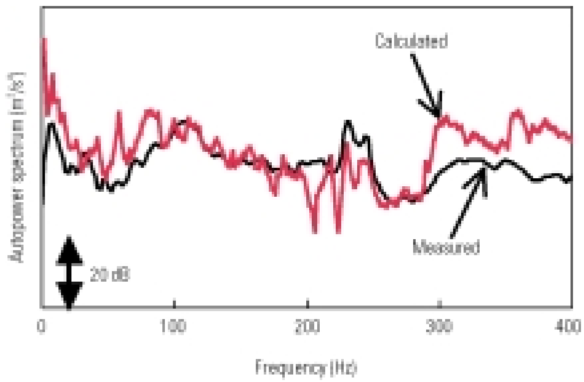

Fig. 8 Validation of predicted body vibration

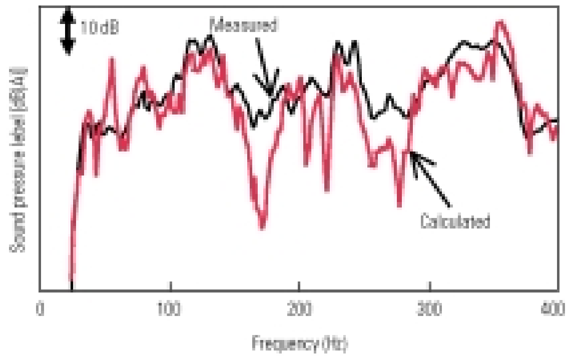

Fig. 9 Validation of predicted interior car noise

formed at the development stage when suspension specifications are selected.

4. Summary

In pursuit of a technique for predicting road noise quantitatively at the development stage when suspension specifications are selected, as useful input for numerical simulations, a function called equivalent road roughness was proposed.

Next, the equivalent road roughness was experimentally identified. It was confirmed that the equivalent road roughness could be identified with adequate accuracy. It was verified that inputs in the vertical direction make the highest contribution to road noise and that, regardless of differences between suspension system, in case of the tire is the same, identified equivalent road roughness are approximately the same.

Finally, suspension vibration and interior car noise were calculated using the identified equivalent road roughness. In this case, it was assumed that the suspension system used for measurement is different from the suspension system used for experimentally identifying the equivalent road roughness. From the results, it was determined that the proposed equivalent road roughness is useful to comprehend road noise quantitatively and qualitatively.

5. End note

The authors wish to express their gratitude to the Yokohama Rubber Company, personnel who assisted with creation of tire models. They also wish to express their gratitude to everyone who advised them on execution of simulations.

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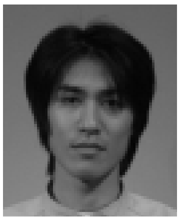
Takashi SHIBATA


Toshihiko SUGAHARA

MITSUBISHI AUTO GALLERY
— Vehicles Which Mark An Era —

COLT 1000 (1964)

Overall length: 3,820 mm	Wheelbase : 2,285 mm
Overall width : 1,490 mm	Displacement: 977 cc
Overall height: 1,420 mm	Horsepower : 51 ps

MITSUBISHI's first genuine 4-door popular sedan. Mounted with Mitsubishi's first water-cooled, series-type 4-cylinders, high-speed high cam shaft engine. Incorporating a flat-deck, box-type design which was very popular at the time, this model won all of the top four prizes at the "2nd JAPAN GRAND PRIX for CLASS III TOURING CARS".

New Technologies Developed for the New COLT for Europe

Golden steering wheel award in 2004

Norifumi MIKAMI* Kunio TAKAOKA* Shiro MORITA* Ken KATAOKA*
Masahiro KANEDA* Masahiro INOUE* Akihiro HARADA*

Abstract

The version of the Mitsubishi COLT for Europe came into being through development and production processes that were not adopted with the version for Japan. The vehicle was jointly developed with DaimlerChrysler (DC) and smart, so the work performed to realize these processes provided priceless experience in terms of both technological cooperation and communication.

Notably, Mitsubishi Motor R&D of Europe (in Helmond, the Netherlands) formed a crucial base for realizing the special processes through day-to-day technical and communication-related support within a group of partners consisting of the Mitsubishi Motors Car Research and Development Center (in Okazaki, Japan), NedCar, smart, MDC-Power, DC, and suppliers.

The special processes are behind the quality that has earned the COLT the German 'Golden Steering Wheel' and other European accolades. This report describes their key technological and communication-related aspects. It is hoped that the information will be useful when further new development and production processes are devised inside and outside Japan.

Key words: *High Strength, System Supplier, Module, Network, Integration, Joint Development, Communication*

1. Hot-stamped bumper beam

1.1 Technology overview

Hot stamping is a production method, aimed at lightness, whereby high-strength sheet steel, which cannot easily be formed using the conventional pressing method, is heated to a high temperature to realize formability and concomitant design freedom. A further benefit is that workpieces can be stronger after being hot-stamped than before (**Fig. 1**).

With the new COLT for Europe, this specialized method was used to satisfy conflicting demands for impact resistance (essential for compliance with requirements related to Euro NCAP frontal-impact tests and German insurance rates) and lightness.

1.2 Key aspects of development

The supplier of the hot-stamped bumper beam, the German company Benteler, played a significant role in the development process. Notably, the supplier, in the process of shape selection for the component, performed repeated CAE analysis not only with respect to the component but also with respect to body deformation.

The technological study for the component began with the assumption that the component's structure would be based on that used with the new COLT for Japan. As the study addressed details of the component, however, additional requirements for shape precision (the component is actually welded onto the body as a front-end crossmember) (**Fig. 2**) and lightness became apparent. Development was at a stage where even a small change in component shape could have had a significant effect on body deformation.

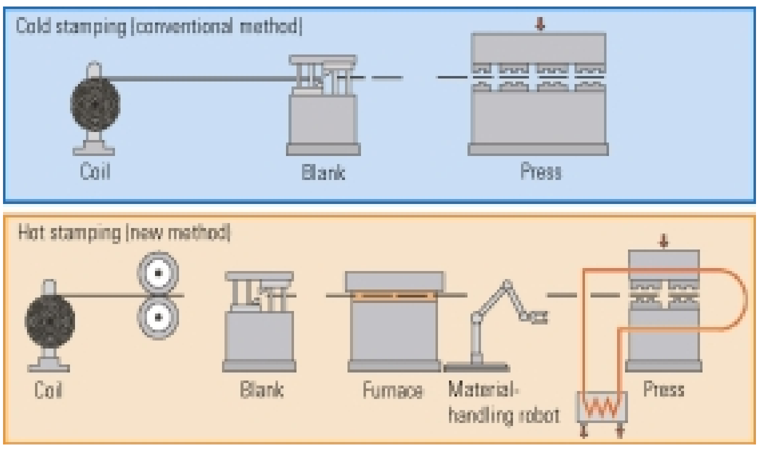

Fig. 1 Hot stamping and cold stamping

* Helmond Designing Dept., Mitsubishi Motor R&D of Europe (MRDE)

Fig. 2 Hot-stamped bumper beam

Adequately timely selection of the final component shape would not have possible had studies and discussions been conducted among the three relevant parties: the Mitsubishi Motors Car Research and Development Center (in Okazaki, Japan), Mitsubishi Motor R&D of Europe (in Helmond, the Netherlands), and Benteler (in Germany). For this reason, the unprecedented decision was made to resolve the matter by entrusting the task of body-deformation analysis to the supplier. The final result was a component weighing 30 % less than the Japan-specification one and costing (in terms of the euro-yen exchange rate at the time in question) approximately the same.

The structure of the component's body mounting points, which are of primary importance in a collision, is the subject of a German patent application filed jointly by Mitsubihi Motors Corporation (MMC), Benteler, and PDE Automotive (a Benteler group company based in Helmond, the Netherlands).

2. Front-end module

2.1 Technology overview

The front-end module of the new COLT for Europe incorporates the ① headlamps; ② radiator and related pipes; ③ air-conditioner condenser and related pipes and sensors; ④ hood support rod and lock stay; ⑤ horn; ⑥ airbag sensors; ⑦ air guide panel; and the plastic frame that holds all of these items. It also incorporates mounting structures for other components located in the vicinity (**Fig. 3**).

The module assembly line (operated by Peguform) is located in the immediate vicinity of the vehicle assembly line at the NedCar plant in Born, the Netherlands, so the cost of transporting the large modules is minimized. Another merit of this arrangement is that information on the fit of headlamps and related parts can be promptly fed back to the staff assembling the modules, meaning that less improving work to achieve high build quality needs to be done on the vehicle assembly line.

2.2 Key aspects of development

At the start of development, the makers of the aforementioned parts ① through ⑤ and the supplier of the module (including the plastic frame) were separately selected.

This arrangement contrasted with the usual module concept, whereby the module supplier (tier 1) is first selected and the component suppliers (tier 2) are then selected such that the tier-1 supplier's responsibility

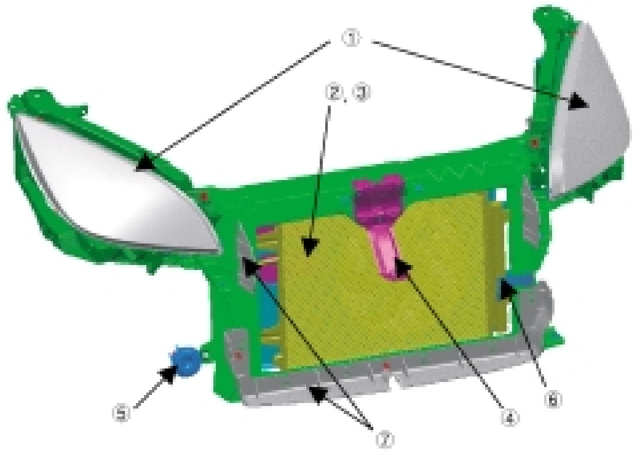

Fig. 3 Front-end module

with respect to the component parts is clear.

As a result, the module and the components were developed separately, meaning that there was a certain amount of inefficiency in terms of time. Also, it is undeniable that there was room for better structural rationalization (integration). (At the time of writing, steps are being taken to improve profitability.)

On the upside, by not entrusting the entire development project to the module supplier MMC gained knowledge about the structural details and material properties of plastic frames.

3. Cockpit module

3.1 Technology overview

The cockpit module for the new COLT for Europe consists mainly of the following items: ① instrument panel; ② heater blower and air-conditioner unit; ③ cross-car beam; ④ steering column; ⑤ engine & compartment wiring harnesses; ⑥ sheet-metal firewall; ⑦ dash-panel pad; ⑧ pedals; and ⑨ master vacuum brake booster. It is attached to the body by means of the firewall and cross-car beam (**Fig. 4**).

3.2 Key aspects of development

As with the front-end module, the component manufacturers and module supplier were separately selected at the beginning of the development process. The demerits of this approach were as described for the front-end module.

A key merit was that, since specification tests with respect to heat resistance, noise, resonance, and air distribution were performed on a module-unit basis, it was possible to identify and rectify problems quickly. By means of the noise tests, it was possible to realize noise-free operation without measures such as the addition of felt. Further, head-impact testing on the module from development through certification was systematically outsourced to JCI; close development liaison with the certification body enabled the instrument panel to be given a stylish design together with full regulatory compliance.

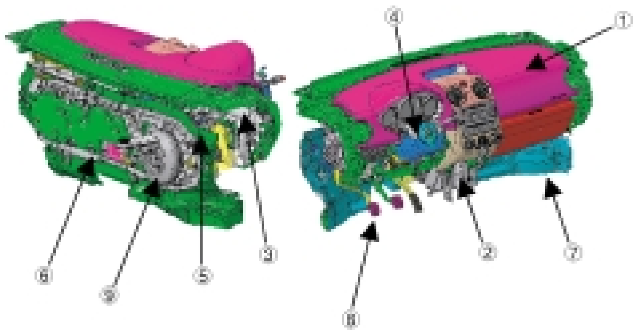

Fig. 4 Cockpit module

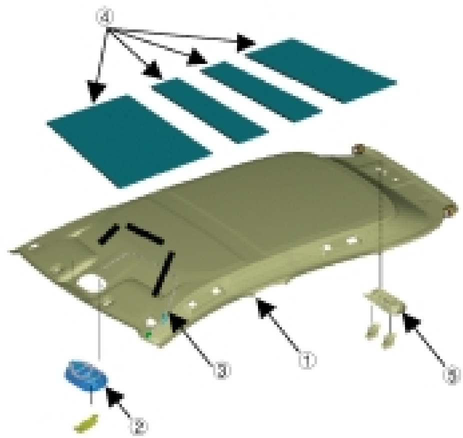

Fig. 5 Headlining module

4. Headlining module

4.1 Technology overview

The headlining module consists mainly of the following items: ① headlining; ② room lamp; ③ roof wiring harness; ④ roof pads; and ⑤ rear-seatbelt tongue holder. It is attached to the body by means of the separately attached sunvisors and assist grips (**Fig. 5**).

Both the cockpit module and the headlining module are assembled on a module line operated by JCI inside the NedCar plant in Born, the Netherlands. For each vehicle, the cockpit module is supplied from the Johnson Controls line to the NedCar line by a conveyor and automatically inserted and mounted in the body by a robot. The headlining module is supplied to the side of the NedCar line and then lifted into the vehicle and mounted by two workers. With this arrangement, the cost of transporting the large modules is minimized, information on the fit of interior parts can be promptly fed back to the staff assembling the modules (meaning that less improving work to achieve high build quality needs to be done on the vehicle assembly line), and function checks on electrical components can be performed on a module-unit basis; quality is concomitantly greatly enhanced.

4.2 Key aspects of development

Early in the development process, the sunvisors and assist grips were also included in development of the headlining module. To realize greater ease of handling within the plant (for example, to prevent the headlining from getting bent) with minimal cost, however, the number of components in the module was reduced. As a result, the headlining represents a good balance of quality and cost.

5. Vehicle network

5.1 Technology overview

The COLT for Europe contains a body-based Local Interconnect Network (LIN) in addition to a Controller Area Network (CAN) of the type earlier adopted by MMC in other vehicle models; the resulting network is more advanced than that of any earlier Mitsubishi vehicle model.

Adoption of such an advanced network made distribution of functions, reduction of cost, and reduction of weight possible. However, the network's complexity created the challenge of ensuring reliability.

5.2 Key aspects of development

(1) Communication between engineers

Since changes in the specifications of communication data has the potential to affect the transmission electronic control unit (ECU) and/or all reception ECUs, coordination between all relevant engineers was essential during development. The COLT's development spanned numerous bases (suppliers outside Japan, suppliers in Japan, smart, and MMC), so the necessary coordination on data specifications was led by Mitsubishi Motor R&D of Europe and PDE Automotive.

(2) Evaluation of validity of communication data (bus load, delay time, etc.)

When coordination on data specifications was complete, evaluation of bus load and message delay time was performed by means of simulations. The communication data specification was then changed as necessary and orders were issued to have them implemented in the ECUs. This process made it possible to prevent message delays and other malfunctions from occurring after production of the ECUs.

(3) Management of communication data

With the COLT for Europe, smart-unique ECUs, MMC-unique ECUs, and common ECUs were developed in parallel, creating the need for smart and MMC to both revise communication data. Consequently, it was necessary for smart and MMC to manage communication data by means of a shared database. As a solution, the CANdis system developed by DC was adopted at an early stage for consistent data management by smart and MMC.

(4) Definition of error-free communication data

To prevent errors in communication, it was essential to define the communication data and implement them in the ECUs. The necessary checks were ultimately performed using actual ECUs.

Further, prior to vehicle fabrication at each stage of development, the suppliers all gathered in single location and together performed bench tests to verify whether data were interpreted in accordance with their definitions, thereby realizing error-free definition of

Photo 1 Bench checks with suppliers

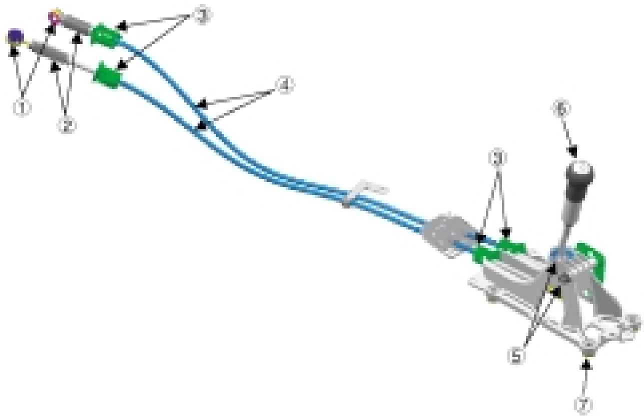

Fig. 6 Manual-transmission gearshift control

communication data and error-free implementation of the data in the ECUs (**Photo 1**).

(5) Start and finish of communication (sleep and wake-up)

The network contains ECUs that operate when the ignition switch is turned OFF and ECUs that operate when the ignition switch is turned ON. Unless each ECU starts or stops communicating in accordance with the communication standard when the ignition switch is turned ON or OFF, the battery can go flat and communication errors can occur.

With the COLT for Europe, bench tests were first performed to verify whether communication started and stopped in accordance with the communication standard. Then, network management including erroneous wakeups caused by noise was checked on an actual vehicle. For the checks, a communication tool was used to monitor the actual communication data. From the observations, it was determined whether communication was starting and stopping normally.

With future vehicle models, networks will likely need to be even more advanced and complex. Using the kind of communication techniques and advanced development tools described above, however, efficient development of vehicle networks will be possible.

6. Manual-transmission gearshift control

6.1 Technology overview

With the COLT for Europe, items ① through ⑥ listed below were adopted by MMC for the first time (**Fig. 6**).

Each of the items listed below is a supplier's standard part or a standard-design part.

① Cable end: Ball-shaped one-touch type (for superior ease of installation)
② Rubber boot: Type with breather hole (for low friction)
③ Cable socket: Cast-plastic type (for lightness and low cost)
④ Cable: Type with band-wound inner wire (for low friction)
⑤ Bearing bush: Plastic one-touch type (for superior ease of installation)
⑥ Shift knob: One-touch-mounted type (for superior ease of installation)
⑦ Insulator and distance piece (for superior noise, vibration, and harshness performance)

6.2 Key aspects of development

The greatest possible use of suppliers' standard parts realized a low cost. Of course, this approach necessitated the adoption of numerous parts that had never been used by MMC and did not satisfy MMC' evaluation criteria. By collecting information on suppliers' track records in the European market, collecting information on suppliers' design concepts, collecting information on other automakers' use of parts made by suppliers, and having thorough discussions with suppliers about its needs, however, MMC was able to select and adopt appropriate parts. This process required more development time, effort, and patience than making dedicated, new parts would have done. However, the knowledge gained through this process can be expected to form an extremely useful resource for future development efforts. The outcome with the new COLT for Europe was that MMC was able to use standard parts and standard-design parts in all areas except those related to styling and those related to COLT-specific mounting.

7. European development of rear torsion axle (joint development with Benteler)

7.1 Technology overview

To enable the COLT for Europe to meet the market's expectations for handling stability, new suspension components were jointly developed by MMC and Benteler (**Fig. 7**).

Major differences from the Japan-specification arrangement are as follows:

(1) The beam was changed from a U-section open structure to a V-section tubular structure (patented by Benteler).
(2) A structure in which a stabilizer function is located within the beam was changed to one in which the stabilizer function is integrated into the main body of the beam (patented by Benteler).
(3) The axle brackets were changed from components that are pressed to components consisting of plates

Fig. 7 Torsion axle: Japan specification vs. Europe specification

welded together.

Revisions (1) and (2) realized rigidity and durability increases over the original arrangement. They also created a degree of freedom for setting of the beam's torsion center (this affects handling stability), making it possible to alter the car's character by design. The new suspension arrangement has the potential to be applied to multiple vehicle models with only small revisions.

Although the COLT for Europe has more or less the same layout as the COLT for Japan, the new suspension arrangement permitted the roll-center height to be made 20 mm higher for better and permitted 5 % lower weight and 10 % higher rigidity.

The new suspension arrangement has started to be adopted in Japan. Since it requires specialized production techniques, however, few prior cases of its adoption existed when COLT development began. In Europe, it has been widely adopted by automakers including Volkswagen.

Revision (3) would have been costly to implement in Japan, but Benteler was able to implement it inexpensively. It was a good example of a solution that was inappropriate in one setting but ideal in another.

The major revisions are as described above. Owing to comprehensive design optimization, however, there are actually few other components that are exactly the same as those in the Japan-specification arrangement.

7.2 Key aspects of development

At the beginning of the development program, the Japanese engineers became keenly aware of differences in culture and development methods. Examples are as follows:

- The European engineers would propose structures completely different from those in Mitsubishi drawings.
- The European engineers would not begin production preparations and technology studies before contracts (purchase orders) were complete.
- Differences in language and culture made for poor communication.

It was difficult for the Japanese engineers to correctly convey the intended meaning of 'design requirements'.

And with regard to design drawings, the Japanese engineers realized the huge importance of explaining the reasoning behind proposed structures; the question 'Why?' was asked again and again by supplier-side engineers throughout the development program.

As mutual understanding deepened, however, the rhythm of joint development improved. The supplier-side engineers gave unreservedly of their effort; no matter how many times target values for performance and durability were changed, for example, the supplier-side engineers were quick to come up with ideas, prove them, produce prototypes, and conduct tests, and they would try multiple approaches at the same time.

8. Conclusion

Although the development program did not go smoothly at first, patient communication between the Japanese and European engineers led to quick, strong teamwork that enabled the various challenges to be overcome. Technical support from the staff at PDE Automotive, who are talented speakers of English and German and immensely knowledgeable about the European market, was also crucial.

For the MMC engineers who worked on European COLT development, the project yielded more than just high-quality components; it also gave us new communication skills and a fresh appreciation of the need to look at new things without prejudice, listen carefully to what other people say, and express our own views clearly. We are convinced that the experience has equipped us to handle the next development project with even greater effectiveness and speed.


Norifumi MIKAMI


Kunio TAKAOKA


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Ken KATAOKA


Masahiro KANEDA


Masahiro INOUE


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MMC Sound Creation

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Abstract

The sound that a device emits when it is operated not only indicates that the device has been operated; it also plays a large role in conveying an impression of the device's quality. With an automobile, the sound emitted by the engine during acceleration and the sound made by the doors as they are closed are examples of sounds that greatly influence the automobile's perceived quality and customer appeal. Given that different people perceive sounds in infinitely different ways, however, it is impossible to design an automobile such that a particular sound emitted by it is perceived as equally good by all users. In the research program described in this paper, therefore, an effort was made to clarify the direction of sound creation necessary to enhance the sportiness and refinement that convey one of the Mitsubishi Motors Corporation's (MMC's) DNA. In line with this direction, an effort was made to identify and quantify the requirements for sounds to be perceived by people as comfortable.

Key words: *Sound, NVH*

1. Introduction

Now that more than a century has passed since automobiles first appeared on the road, automobile technology has reached a degree of maturity; automakers must increasingly focus on automobiles' sensual performance (the manner in which automobiles appeal to their users' five senses) to achieve differentiation from competitors.

Exterior styling and interior trim design, which appeal to users' visual faculties, have long been used by automakers to gain a competitive edge through the individual identities that they help to create. Lately, though, more and more automakers are pursuing automobile development with an additional focus on the automobiles' sound, which relates to users' auditory faculties.

In the research program described in this paper, the researchers focused on engine sound (a key element of an automobile's identity) and door-closing sound and pursued sensual performance that people would perceive as comfortable.

2. Direction of sound creation

To form a direction for sound creation, positioning reflecting a highly sporty, powerful, and exciting identity was established in line with the direction of MMC's DNA. Specifically, the positioning was established as 'powerful and exciting' against a vertical axis related to sound quality and a horizontal axis related to sound pressure level (**Fig. 1**).

3. Engine sound

Linear, clear sound quality is necessary to satisfy the 'powerful and exciting' positioning established for sound creation. In this context, 'linear' refers to sound that changes in a linear manner in accordance with changes in engine speed; 'clear' refers to sound that is free of muddiness and impurity.

The sound produced by an engine consists of three main sounds:

(1) The sound of engine itself
(2) Intake sound
(3) Exhaust sound

With regard to the sound of the engine body, a V6 engine emits a characteristic rumbling sound called half-order harmonics besides the fundamental sound such as third-order harmonics. This sound is impure.

With the intake system, it is difficult to achieve a layout in which the intake passages are all the same length, meaning that there is a tendency for half-order harmonics to be produced similar to the engine body. In the research program described in this paper, therefore, it was determined that the exhaust sound would be used to produce a clear, linear sound.

Furthermore, the sound emitted by the main body of the engine and the sound emitted by the intake system would be reduced sufficiently to be masked by the exhaust sound.

3.1 Reduction of the sound of engine itself

The sound emitted by the main body of an engine was reduced by approximately 20 % using the measures shown in **Table 1**.

* Vehicle Proving Dept., Development Engineering Center
** Vehicle Engineering Dept., Development Engineering Center
*** Engine Testing Dept., Development Engineering Center
**** FF Product Development Project C-seg, Product Development Office

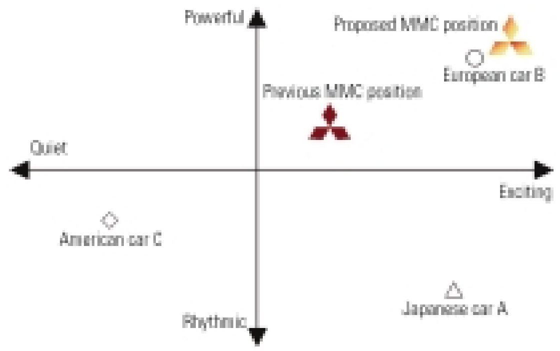

Fig. 1　Direction of MMC sound creation

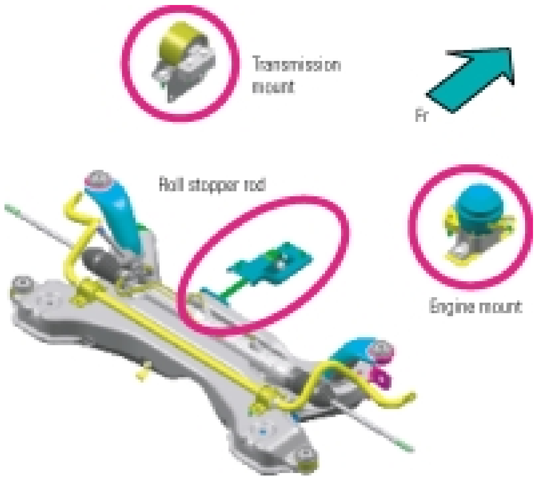

Fig. 2　New three-point engine mounting system

Table 1　Measures taken to reduce engine noise

Part of engine	Measure taken	Benefit
Rocker cover	Metalamine washers added	Radiant sound
Timing belt cover	Material changed	Radiant noise at idle reduced
Crank journals	Journal clearance reduced	Radiant sound and engine vibration reduced
Engine cover	Acoustic material added	Radiant noise above engine reduced
Crankshaft	Pin diameter increased	Radiant sound and engine vibration reduced
Cylinder block	Rigidity increased Lower deck thickness increased Skirt thickness increased	
Connecting rods	Hole diameter increased	
Connecting rod bearings	Diameter increased	

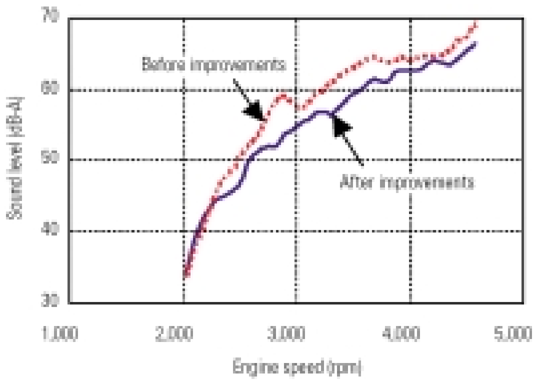

Fig. 3　Engine noise reduction

In addition, the mounting system shown in **Fig. 2** was adopted as a means of reducing vibration transmitted to the vehicle body from the engine.

As a result of the improvements made to the engine itself and the reduction in vibration transmitted to the vehicle body, interior noise was reduced by 3 to 4 dB (**Fig. 3**).

3.2　Sound creation using exhaust sound

Next, the requirements for creating a powerful, exciting, and unconstrained exhaust sound were investigated and identified as follows:

(1) The exhaust sound must be created using only the third-, sixth-, and ninth-order harmonics (the engine's fundamental sound).

(2) The individual sound must not be superimposed upon each other at the same level and must have the same intensity.

(3) The sound must exist throughout the engine's rev range.

(4) The sound level must increase at a fixed ratio as the engine speed increases through the rev range.

In accordance with these requirements, tuning was performed as shown in **Fig. 4**.

The tuning of the exhaust sound intensifies at frequency in the yellow area by main muffler's expansion chamber and resonance makes the ninth-order harmonics increase at low engine speeds, the sixth-order harmonics increase at mid-range engine speeds, and the third-order harmonics increase at high engine speeds, yielding a continuous, pleasing exhaust sound from the bottom end of the rev range to the top end. As a result, a sporty, and linearly blow-up exhaust sound is created.

3.3　Results of engine sound creation

Tuning of the main muffler to produce sound in the 150 – 300 Hz range yielded the desired sound. Two pre-mufflers to control the sound level and the manner in which sound rises to peaks were then added to the exhaust pipe (**Fig. 5**).

It was thus possible to realize a clear sound that changed in a linear manner from the bottom end of the rev range to the top end (**Fig. 6**).

4.　Door-closing sound

The door-closing sound of most Japanese automobiles is soft and muffled, with mechanical tones maximally excluded. As a means of differentiating MMC

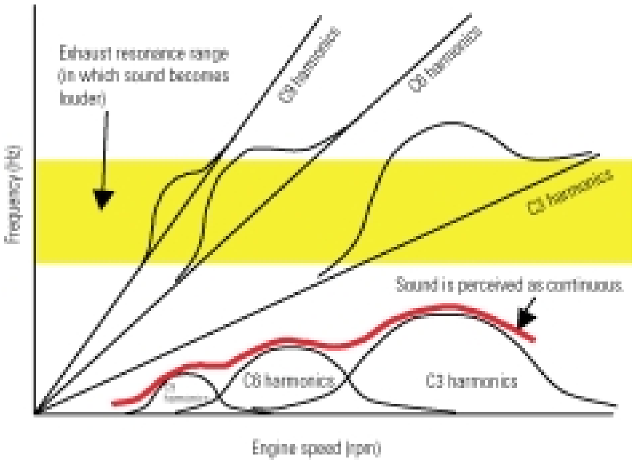

Fig. 4　Exhaust sound tuning

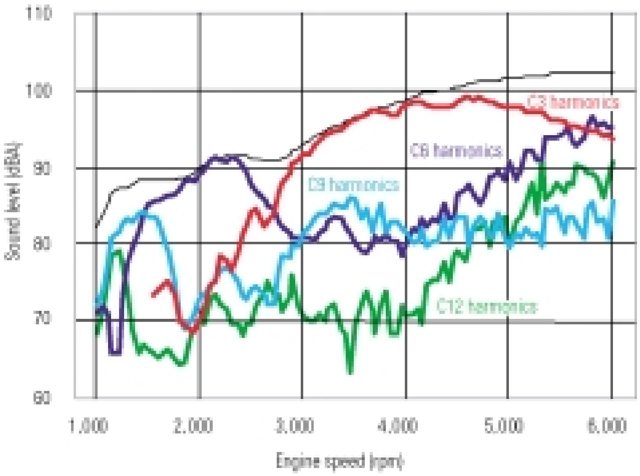

Fig. 6　Results of exhaust sound tuning

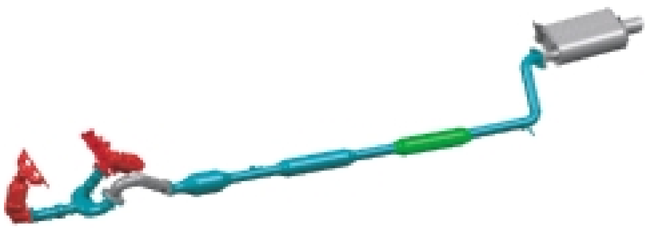

Fig. 5　Two pre-mufflers in exhaust pipe

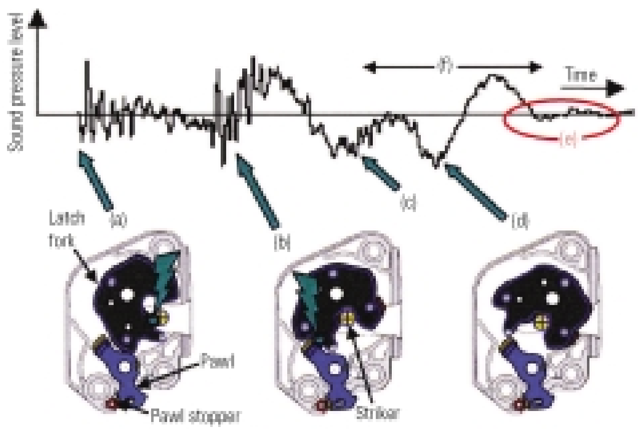

Fig. 7　Emission of door-closing sound

automobiles from other Japanese automobiles in line with the sound-creation direction described earlier in this paper, a relatively firm, sharp, mechanical door-closing sound was proposed.

4.1　Mechanism of door-closing sound

The mechanism by which door-closing sound is produced is shown in **Fig. 7**.

(a) A knocking sound produced by the striker and latch fork
(b) A knocking sound produced by the half-groove of the latch fork and the pawl
(c) A knocking sound produced by the rubber damper and the body panel
(d) A knocking sound produced by the pawl stopper (overrun condition)
(e) A knocking sound produced by the return movement that takes place as a reaction from overrun (full latching)
(f) A reverberation of the knocking sound produced by the weatherstrip and body panel

Mechanical tones are typically minimized using a sound-muffling structure including a hollow center in the plastic coating on the latch fork (this relates to sound elements (a) and (b) above) and rubber on the stopper (this relates to sound element (d) mentioned above).

4.2　Creation of door-closing sound

Causing two sound elements to be produced with a certain difference in timing between them made it possible to create a solid sound that, notwithstanding its mechanical quality, conveys depth and sophistication. To stage such a mechanical sound, it is decided to increase the sound pressure level of the sound elements labeled (a) and (b) in **Fig. 7**. (These sound elements have mechanical tones.) The conditions for this sound-quality tuning are as follows:

(1) Sound elements (a) and (b) must be louder than other sounds and have approximately the same sound pressure level as each other.
(2) The sound quality (peak-frequency band) must be similar.
(3) The sound quality of sound elements (a) and (b) must be harmonic (with multiple frequency peaks occurring at equal intervals) and at the lowest possible frequency (3 kHz or lower).
(4) There must be no more than a certain time difference between the occurrence of sound element (a) and the occurrence of sound element (b).
(5) The reverberation (sound element (f)) must be as short as possible.

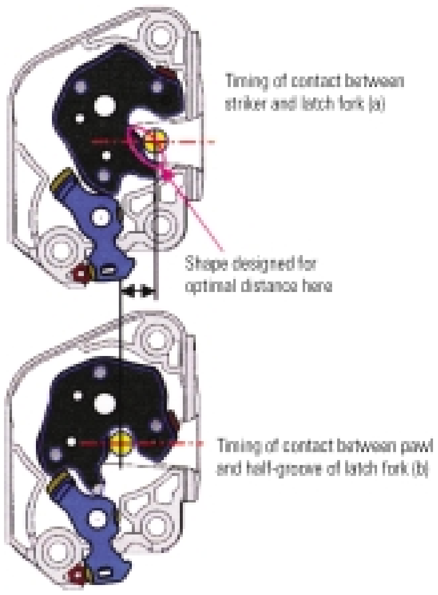

Fig. 8 Latch design requirements (for optimal time difference between sound elements)

4.3 Results of door-closing sound creation

In accordance with the aforementioned conditions, the door latch was revised, with the result that the intended sound was achieved (**Fig. 8**).

In **Fig. 9**, a conventional door-closing sound is compared with the newly proposed door-closing sound.

Since the conventional development is to simply minimize sound, in the mechanism of door-closing sound, two aforementioned key sound elements (a) and (b) are totally different from each other and occur with too great a time interval between them. Thus the result is a flimsy and monotonous sound.

With the newly proposed arrangement, two sound elements (a) and (b) have the same harmonics and occur with an optimal time interval between them, resulting in a refined mechanical sound.

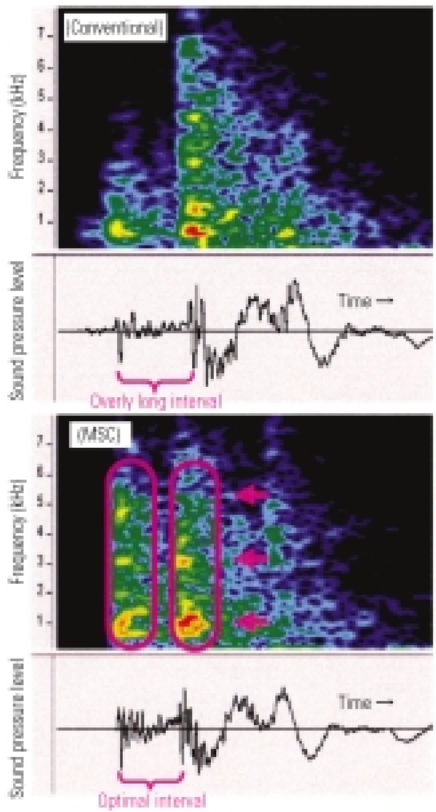

Fig. 9 Conventional and newly proposed door-closing sounds

5. Evaluation by typical automobile users

The newly proposed engine sound and door-closing sound were evaluated by 100 typical automobile users in a clinic as described below.

(1) Clinic methodology (**Fig. 10**)

Clinic participants listened to the engine sounds through headphones while watching a video of the view that they would see from the cabin of an accelerating automobile.

Further, the participants listened to the door-closing sounds through headphones while watching a video of the door being closed.

All participants were shown the same videos to ensure that their evaluations were not differently affected by different images.

(2) Subjects used in comparisons (**Fig. 11**)

We prepared the sounds of three typical competing vehicles.

Fig. 10 Clinic

The results of the clinic showed that the newly proposed sounds were consistent with the intended 'powerful and exciting' positioning and that they were an extremely effective means of achieving differentiation from competing vehicles.

6. Conclusion

Normally, structures are designed to simply reduce noise to the greatest possible extent. In the research program described in this paper, by contrast, 'powerful and exciting' positioning was proposed for sound creation and the challenges of actively producing sound

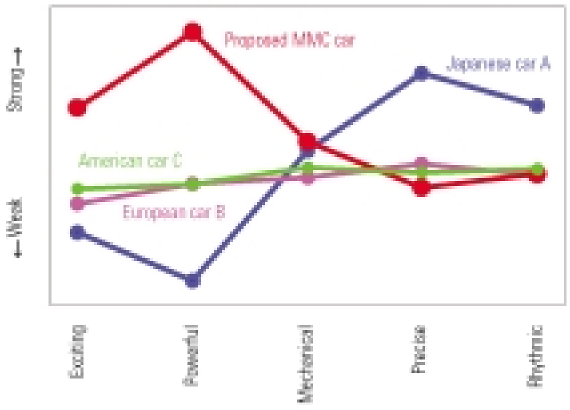

Fig. 11 Clinic results

that would be perceived as appealing were addressed in line with the proposed positioning.

Notwithstanding the fact that different people have infinitely different preferences, the research program yielded sound that has the potential to enable many automobile users to enjoy a sporty, exciting driving experience.

7. Acknowledgments

The authors wish to express their sincere gratitude to all personnel, both within MMC and at suppliers (NOK CORPORATION, Sakamoto Industry Co., Ltd. and ANSEI CORPORATION), who collaborated in the development work for MMC's new sound creation.


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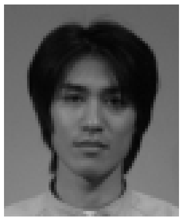
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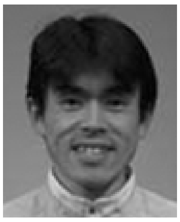
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Development of Technique for Estimating Suspension Input Force During Endurance Run on Rough Road

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Abstract

To estimate the endurance service life of an endurance-run vehicle on a rough road by use of computer-aided engineering (CAE), it is essential to determine the stress on various parts of the vehicle during the run and the force applied to it (input force). We simulated an endurance run by CAE and developed a technique for estimating the input force. The estimated results closely matched the results of an experiment. We found that it is possible to estimate the input variation with the specifications for the suspension.

Key words: *Durability, Computer-Aided Engineering, Numerical Analysis*

1. Introduction

There is strong demand for reductions in the weight, cost, and development period of motor vehicles without sacrificing safety and quality. Front loading by CAE is one of the important means for achieving these objectives. An endurance test on a company-owned test course, which is expensive and time-consuming, has to be made to ensure the required durability and safety for vehicles. Hence, a virtual endurance test by CAE is needed to justify the vehicle structure and the suspension characteristics at an early stage of development.

The following two techniques are required to replace a real endurance test with a virtual one:

(1) Technique for estimating the force applied to various parts of the endurance run vehicle (input force).
(2) Technique for estimating the service lives of parts of the vehicle by calculating the stress on those parts from the input force and determining the magnitude of stress and the number of times it is imposed.

We studied a CAE estimation method in the first of the above two categories. A vehicle model was made to run on a virtual road reproduced with high fidelity on the computer, and the input was estimated (**Fig. 1**).

2. Road model

2.1 Study of methods

We examined the following three methods of applying the input derived from the convex and concave surface of the road to the vehicle model created by CAE:

(1) High-fidelity reproduction of the surveyed three-dimensional convex and concave surface contour on the computer and the running of a vehicle model created by CAE on the simulated road.
(2) Simulation on the computer of the road by deriving a random convex and concave surface contour from a two-dimensional (vertical, longitudinal) convex and concave contour power spectrum and the running of a vehicle model created by CAE[1].
(3) Determination of the road contour from the loads on the axles of a real car and the application of that contour to a vehicle model created by CAE[2].

For method (2), we concluded that the vertical force

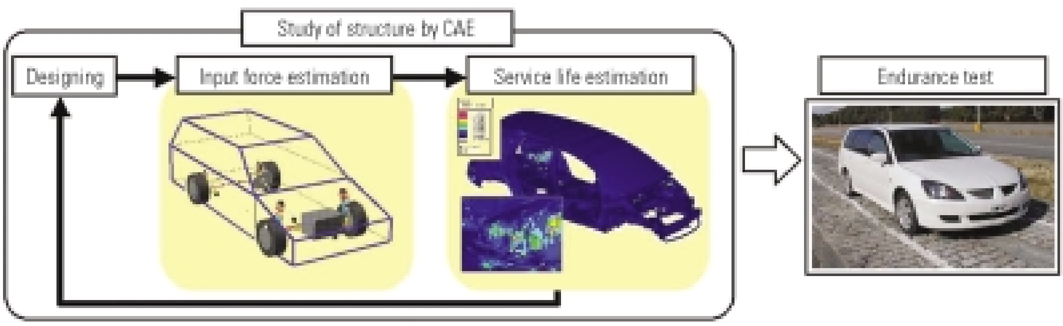

Fig. 1 Flowchart of endurance strength research by CAE

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and the longitudinal force could be estimated because the road surface is two-dimensional, but the lateral force is hard to estimate.

For method (3), we presumed that the contour would not be well reproduced when tires of the car lose contact with the road. When the car is running on a rough road which is convex and concave in many parts, the tires frequently lose contact with the road.

Method (1) involves three-dimensional reproduction of the road surface, and we expected that the longitudinal force and the lateral force, which are considered to be relatively hard to estimate, could be estimated by using this method. High-fidelity reproduction of a road surface requires a vast amount of data, but this can now be handled easily by modern computers and so we selected method (1).

2.2 Determination of convex and concave contour

A key factor in determining the convex and concave contour of the surface of a road is true-to-life reproduction of the contact areas of the road surface with the vehicle model's tires. A small enough pitch compared with the tire size is therefore essential, so we used a photographic survey which allows for such a slight pitch.

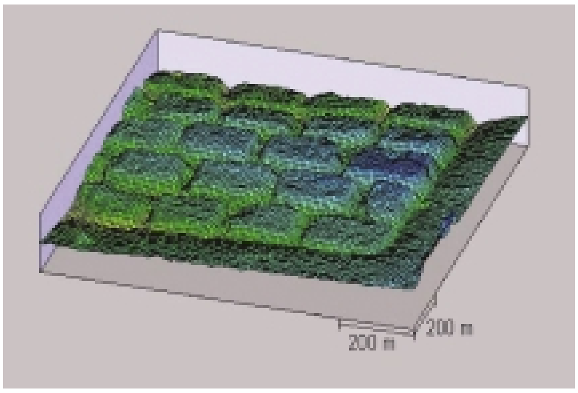

Fig. 2 Typical convex and concave road surface data

A photographic survey reproduces a three-dimensional form by using two photos taken of an object from different angles.

Typical convex and concave road surface data obtained by photographic survey is presented in **Fig. 2**.

3. Analytical model

We adopted MSC's mechanical analysis software ADAMS for CAE analysis[3].

3.1 Vehicle model

Our vehicle model is based on a station wagon equipped with the McPherson-Strut front suspension and a multi-link rear suspension. The parts for the body, power train, suspensions and steering are treated as rigid parts. Rubber bushes and shock absorbers are used as interlinking means to accommodate the non-linear shape (**Fig. 3**).

We used the Ftire model, which is suitable for three-dimensional analysis with a relatively high calculation speed, among other commercially available tire models[(4) – (6)].

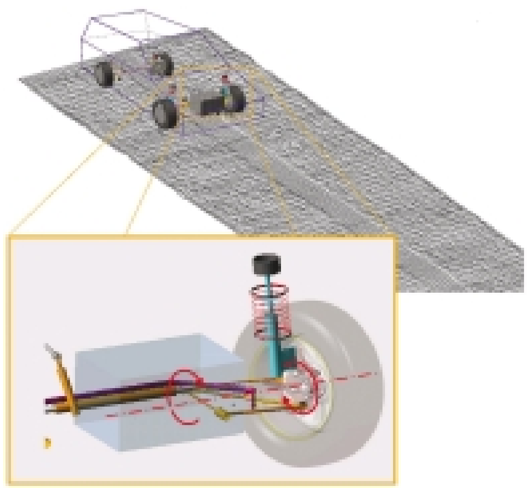

Fig. 3 Diagram of vehicle model and driving torque

3.2 Vehicle speed control

Driving torque is supplied to the hub to increase the vehicle speed when the speed is below the target level, as a way to control the speed. Reverse torque is supplied to the power train as reaction to the driving torque (**Fig. 3**).

3.3 Steering control

Our steering control is based on the forward error correction model involved in the primary estimation. As shown in **Fig. 4**, if a certain point at a fixed distance ahead of the present position of the vehicle is laterally off the target course, the steering angle is adjusted according to the extent of deviation.

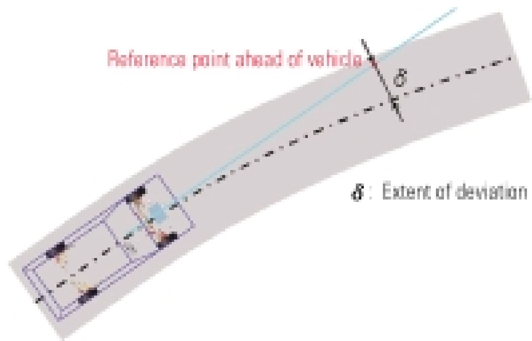

Fig. 4 Steering control

4. Results of input force estimate analysis

4.1 Estimation accuracy

The results of the analysis and the results of experiment are compared in **Fig. 5** to **7**. **Fig. 5** shows the vertical force in the area where a shock absorber was installed (called "vertical force" hereafter), **Fig. 6** the longitudinal force applied to the lower arm (called "longitudinal force" hereafter), and **Fig. 7** the lateral force applied to the lower arm (called "lateral force" hereafter). The vertical force and the longitudinal force were calculated accurately.

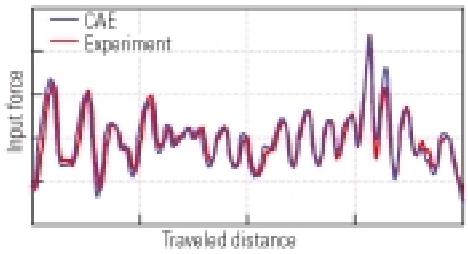

Fig. 5 CAE-to-experiment comparison: vertical force in area where shock absorber was installed

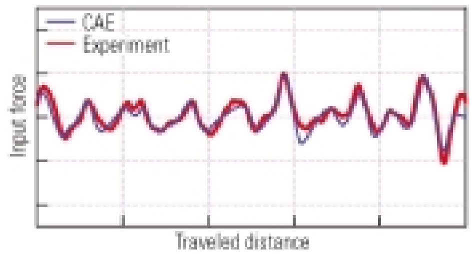

Fig. 6 CAE-to-experiment comparison: longitudinal force applied to lower arm

The accuracy of lateral force estimation is lower than those of vertical force and longitudinal force estimations. However, the initial target set based on practical aspects was virtually attained.

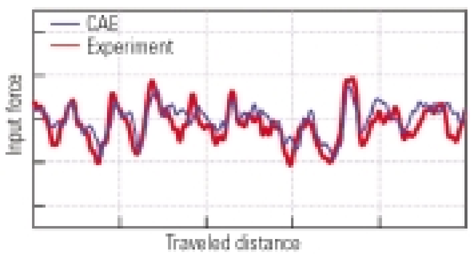

Fig. 7 CAE-to-experiment comparison: lateral force applied to lower arm

4.2 Variation with part of road on which vehicle runs

The experiment data for the vehicle running close to the center of the road are compared with those for the vehicle running off the center (offset run) in **Fig. 8**. This indicates that the input varies with the part of the road on which the vehicle runs.

An analysis of the run off the center of the road (**Fig. 9**) shows the same variation.

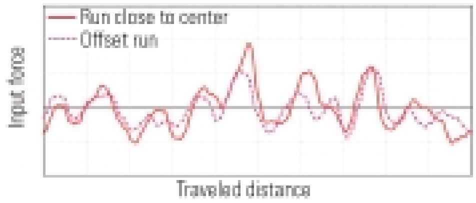

Fig. 8 Input force variation with part of road on which vehicle runs – experiment –

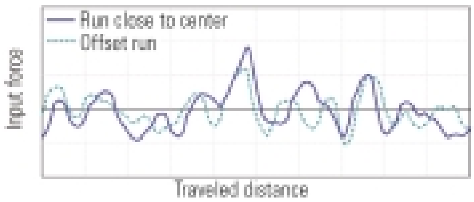

Fig. 9 Input force variation with part of road on which vehicle runs – CAE –

This indicates that the three-dimensional convex and concave contour of the road surface was accurately reproduced.

Hence, an input force estimation can be made based on these data for a vehicle with a different wheel track.

Thus it was found that the input force could be estimated with very high accuracy for individual runs if the part of the road on which the vehicle runs is taken into account.

Various paths of run and various vehicle speeds in an actual endurance test can all be analyzed. The estimated change in frequency of application of the vertical force with the passage of time closely matches the result of an experiment related to that frequency (**Fig. 10**). Thus the analysis can provide the base data for a statistical presentation.

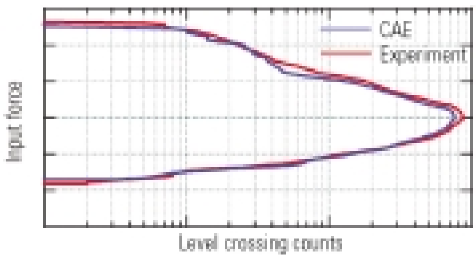

Fig. 10 CAE-to-experiment comparison: vertical force in area where shock absorber is installed

4.3 Input force variation with specifications

It is widely known that the fatigue service life varies widely with the specifications if two or more sets of specifications such as standard specifications and sports specifications are provided for a particular model, such as the attenuation characteristics of shock absorbers. It is important in practice to estimate an input force change for the endurance strength according to the attenuation characteristics of shock absorbers and the characteristics of the suspension, and to estimate the effect of that change.

The input force were determined by CAE and through an experiment for specifications A and specifications B, which may vary in suspension characteristics, and the pseudo fatigue damage was mathematically determined. It was calculated by the elementary Miner's rule, applying an imaginary S-N curve to counting results of the input force.

Fig. 11 compares the damage from fatigue in the case of specifications A with those of specifications B, as determined by CAE and through the experiment. The figure shows that the input force presented in terms of the pseudo damage was estimated with high accuracy in respect of not only the vertical force and the longitudinal force but also the lateral force.

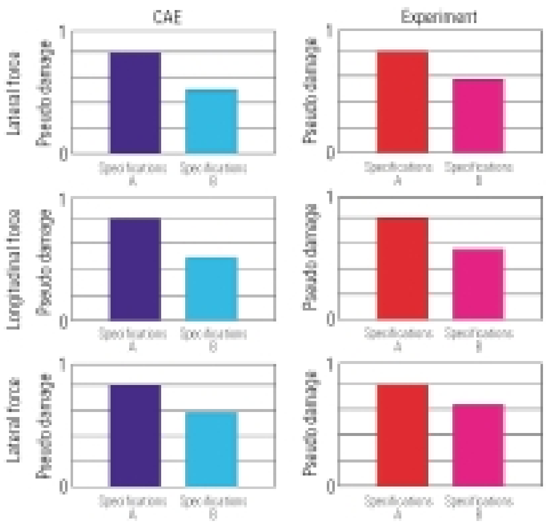

Fig. 11 Pseudo damage – comparison between specifications A and specifications B

5. Conclusion

This method is widely applicable irrespective of the vehicle specifications and will be an effective tool for vehicle development.

Finally, we sincerely thank those concerned inside and outside the company for helping to develop the technique.

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NEW TECHNOLOGIES

Development of Key Registration System Using Barcode

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Moriyasu MATSUNO* Yoko IKURA*

Abstract

Immobilizer IDs and keyless entry IDs stored in the memory of ignition keys had to be registered at the works and the registration procedure was complicated, so barcode registration by using Controller Area Network (CAN) communication system in ECUs was used to overcome this problem. This method enables these IDs to be registered simultaneously and so reduces the registration time by 65 %. The method is not affected by radio interference during key registration or environmental noise, and prevents key registration errors.

Key words: *Barcode, Immobilizer, Keyless Entry, Key, Registration*

1. Introduction

An ignition key has IDs, which enables the immobilizer function and keyless entry function to be used in a vehicle, key number and other information specific to the individual key. An operator at the works must register these data in the immobilizer ECU and the keyless entry receiver. In the past, individual functions had to be registered for each key of the key assembly, and the procedure had to be repeated for each key assembly. Moreover, key information registration was expected to become even more complicated for passive entry system. In addition, the registration work was done by radio communication and was sometimes unsuccessful due to radio interference between keys and environmental noise.

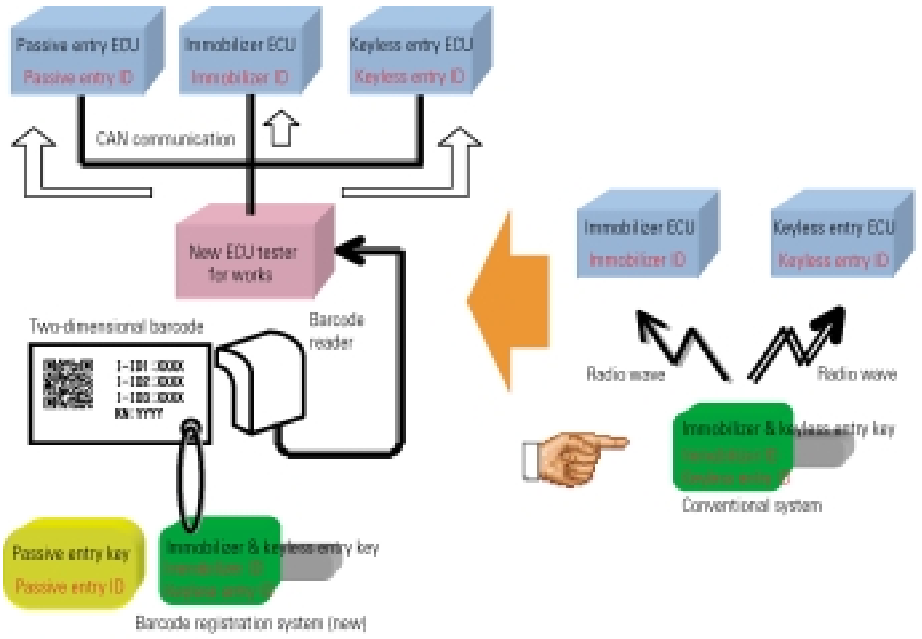

Fig. 1 Equipment used

To overcome this problem, introduction of barcode registration was considered, and which makes it possible to register by only a single action and preclude the possibility of radio interference. Registration of key-related information by a barcode (one-dimension) is now carried out on the COLT production line at the NedCar factory (in the Netherlands). However, we adopted a two-dimensional system which involves a smaller barcode label and larger data storage capacity than in the one-dimensional system, supposing that more data would need to be registered for future vehicle models.

Knowing that the ECU tester for the works which corresponds to CAN communication will be provided, we decided to introduce uniform barcode specifications for the new 06MY models (partly including vehicles with minor changes) and the subsequent vehicles.

2. System configuration

2.1 Equipment used and data flow

The equipment for the conventional system and the equipment for the barcode registration system are shown in **Fig. 1**.

With the conventional system, keys were manually operated, and immobilizer IDs and keyless entry IDs were registered by the radio waves generated by the key operation. To register them, settings with a tester (MUT) were required for the immobilizer ECU, and settings with a special jig and by special operation for the

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Table 1 Key data

Item	Description	Remark
Immobilizer	Immobilizer ID	ID for each key
	Secret key code (SK)	Single code for the key assembly
	Password transponder (PSW_T)	Common password for the Company
	Transponder memory configuration (TMCF)	Common memory configuration for the Company
Keyless entry	Keyless entry ID	ID for each key
Passive entry	Passive entry ID	ID for each key
Key number	Information on the key groove	Single number for the key assembly

Table 2 Barcode data (two-dimensional data)

Item	Description
Header	For identifying the barcode
Status	Specifications for the key assembly: whether particular functions are available or not and the number of keys.
Immobilizer ID	4 bytes x 3, If not used, "00h"
Keyless entry or passive entry	4 bytes x 2, If not used, "00h"
Key number	2 bytes

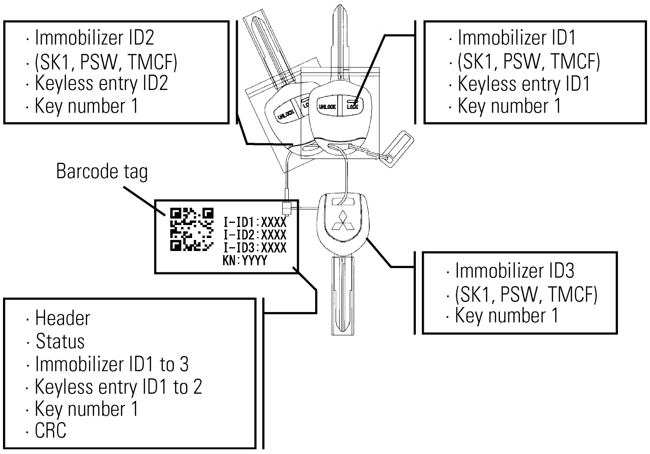

Fig. 2 Keys and barcode data

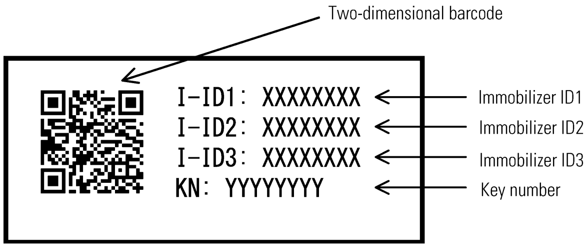

Fig. 3 Barcode tag

keyless entry ECU.

In the barcode registration system, immobilizer IDs and either keyless entry IDs or passive entry IDs and the key number (information on the key groove) are read from the barcode tag attached to the key assembly by the barcode reader of the new ECU tester for the works, and the data are then transmitted to ECUs. ECUs pick out the data necessary to make their functions available from the data received from the tester and store the data.

2.2 Keys and two-dimensional barcode specifications

The data listed in **Tables 1** and **2** are wrote into the keys and the two-dimensional barcode, and the key assemblies are delivered to the works in the state shown in **Fig. 2**.

The two-dimensional barcode has the advantages as follows and which has a good reading reliability and workability:

- Be possible to restore and read data partially lost, soiled or stained in up to 30 % of the area and preserves data well.
- Be possible to reduce the symbol size as data storage capacity per unit area is 30 times that of a barcode.
- Be possible to read the data from all angles with a 360-degree by the black-white-black pattern, which looks like three eyeballs.

The IDs and key number to be registered are random data. In case they are misread, the tester for the works cannot ascertain whether they are the correct data. To prevent this, all barcode data to be registered to the vehicle are accompanied with cyclic redundancy check (CRC), which is an error-detecting code, thus whether the correct data are read from the barcode by the barcode reader can be ascertained. If the barcode reader misreads barcode data, the tester indicates an error on the screen without registering the key information for the vehicle and prompts the operator to re-register the data.

The barcode tag is shown in **Fig. 3**. The symbol of two-dimensional barcode is presented on the left-hand part of the tag, and the immobilizer IDs and key number on the right. These are provided to allow registration of the key information by MUT-3 of the service tester when the key assembly is replaced during post-installation service, with no barcode reader on hand.

3. Effects of barcode registration

3.1 Reduction of man-hours and cost

Man-hour reduction: ▲65 % (See **Fig. 4** for details.)

Major tasks which can be eliminated by barcode registration are:

- Registration of the immobilizer IDs
  - Replacement of keys
- Registration of the keyless entry IDs
  - Setting in the registration mode by operating the hazard switch
  - Operation of the switch for the keyless entry key

Cost reduction: ▲25 %.
(= barcode tag/one harness)

Total cost reduction will be achieved because the cost reduction by reducing the harnesses for MUT and

	Conventional registration system	
	Steps	Percentage (*1)
	1. Immobilizer	
1)	Take MUT-2.	2.5 %
2)	Connect MUT-2 to diagnostic connector.	2.5 %
3)	Ignition switch ON	1.2 %
4)	Register master key by using MUT-2. (Includes time taken to operate MUT-2.)	19 %
5)	Replace keys (with spare keys). (Two keys)	4.9 %
6)	Register by using spare key MUT-2.	37 %
7)	Disconnect MUT-2 from diagnostic connector.	2.5 %
8)	Ignition switch OFF	1.2 %
	Subtotal	70 %
	2. Keyless entry	
1)	Take MUT-2.	2.5 %
2)	Connect MUT-2 to diagnostic connector.	2.5 %
3)	Press hazard switch 6 times.	9.9 %
4)	Operate switch for keyless entry key.	12 %
5)	Disconnect MUT-2 from diagnostic connector.	2.5 %
	Subtotal	30 %
	Total	100 %

	Barcode registration system	
	Steps	Percentage (*1)
	Immobilizer, keyless entry	
1)	Connect new ECU tester to diagnosis connector.	4.9 %
2)	Ignition switch ON.	1.2 %
3)	Register by using new ECU tester. (Immobilizer)	12 %
	Register by using new ECU tester. (Keyless entry)	12 %
4)	Disconnect new ECU tester from diagnosis connector.	2.5 %
5)	Ignition switch OFF.	1.2 %
	Total	35 %

Man-hour reduction: ▲65 %

*1 Percentage of each operation time to the conventional registration time

Fig. 4 Man-hour reduction by barcode registration

special jigs exceeds the cost increment by adding the barcode tag.

3.2 Prevention of radio interference

Under the conventional registration system, key information registration for the keyless entry and the immobilizer was made by radio communication between keys and the vehicle. Sometimes the data were not normally registered due to radio interference between the registering key and other keys, and environmental noise. Hence, the process for registering the key information in the vehicle had to be done at a place relatively unaffected by environmental noise.

Under the barcode registration system, registration is carried out not by radio communication between keys and the vehicle but by CAN communication between the tester and the vehicle. The registration process is no longer affected by radio interference, and registration can be done anywhere.

3.3 Prevention of skip-over

Under the conventional registration system, immobilizer IDs and keyless entry IDs registration was needed for each key of the key assembly, and the same procedure had to be repeated for each of the key assemblies, and the operator sometimes skipped over a key of the key assembly or forgot to registration of immobilizer IDs or keyless entry IDs. In such a case, the omission can be detected by a function verification during a subsequent process. However, extra corrective man-hours were taken to re-register the omitted item.

All pieces of key information are now registered under the barcode registration system at a time, thus eliminating such omissions.

4. Conclusion

The introduction of barcode registration has shortened the working hours and increased reliability.

The new registration system will be used for investigating faults or failures on the market by maintaining records of chassis numbers and registered key information by the way to register the key information in ECUs via the tester. The two-dimensional barcode has surplus data storage capacity, and we hope to register data peculiar to keys in ECUs to enhance users' convenience.

Finally, we thank all those concerned who assisted our development work including personnel in change of assembling engineering.

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Eiji SATO

Toshihiko YAMAZAKI

Moriyasu MATSUNO

Yoko IKURA

Mass Production of Tailored Blanks by Means of Multilinear Joining Technique

Kenji UNO*

Abstract

As demands for environmental protection and crashworthiness continue to grow, automakers are making extensive use of lightweight high-tensile steel in vehicle bodies and are expanding their use of tailored blanks.

Tailored blanks are typically produced using linear joining, but aMitsubishi Motors Corporation (MMC) recently took further steps forward by applying a right-angle joining technique to tailored blanks used for the door inner panels of the COLT and by applying a multilinear joining technique (a technique with which welding is performed in multiple directions) to tailored blanks used for the large side outer panels of the GRANDIS.

Key Words: *Crashworthiness, Weight Reduction, Press Working, Welding*

1. Introduction

Different levels of rigidity, collision performance, and rust resistance are needed in different parts of a vehicle body. Conventionally, automakers have satisfied these requirements by employing reinforcements and rust-resistant steel in appropriate areas. For lightness and economy, however, automakers need to minimize numbers of body components and use inexpensive materials.

Tailored blanks are a means of satisfying the conflicting needs for strength, rust resistance, lightness, and economy. To create a tailored blank, two or more sheets that differ in terms of thickness and/or material are joined together into a single item that is then pressed to achieve inherent structural strength. As a result, tailored blanks dispense with the need for reinforcements and enable thinner material to be used. They also permit costly rust-resistant steel to be used only where absolutely necessary. An example of a tailored blank is shown in **Fig. 1**.

Tailored blanks were pioneered in the mid-1980s by the German steelmaker Thyssen. Japanese automakers first adopted them in the 1990s and have since increasingly used them for inner panels and for frame members.

MMC began making full-fledged use of tailored blanks with the COLT and GRANDIS, which both went on sale in 2002 and 2003. Rather than using the established linear joining technique with its tailored blanks, MMC sought further advantages by adopting a right-angle joining technique and a multilinear joining technique. MMC's techniques and their application to mass production are detailed in this paper.

2. Tailored blanks of COLT and GRANDIS

Conventional tailored blanks are generally used for

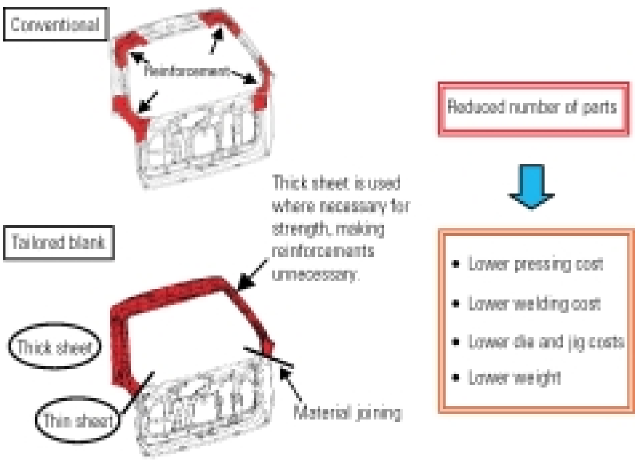

Fig. 1 Merits of tailored blanks (examples)

inner panels and for frame members, and their joints are arranged in straight lines (**Fig. 2**).

Various welding methods such as mash-seam welding, plasma welding, and laser welding are used with tailored blanks. MMC selected laser welding, which causes the smallest thermal effects and is superior in terms of formability.

Usable joining techniques are not limited to the conventional linear technique; they also include the right-angle technique and the multilinear technique (**Fig. 3**). With the right-angle technique and multilinear technique, greater body design freedom allow lower cost and lower weight, but they have not been widely adopted either in Japan or overseas owing to various technological hurdles, which are described later in this paper.

Notwithstanding the technological hurdles, MMC adopted the right-angle joining technique with the door inner panels of the COLT, thereby enhancing the preven-

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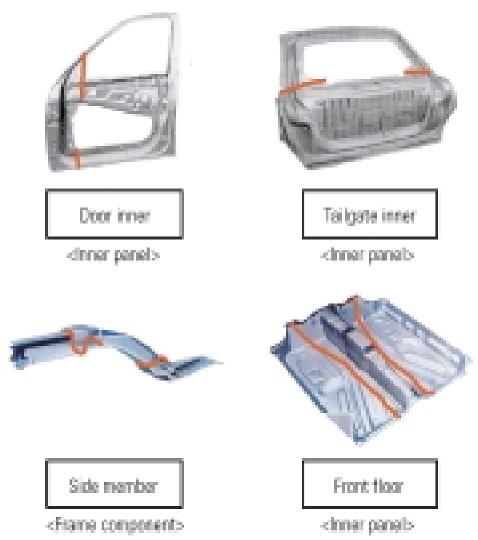

Fig. 2 Use of tailored blanks (examples)

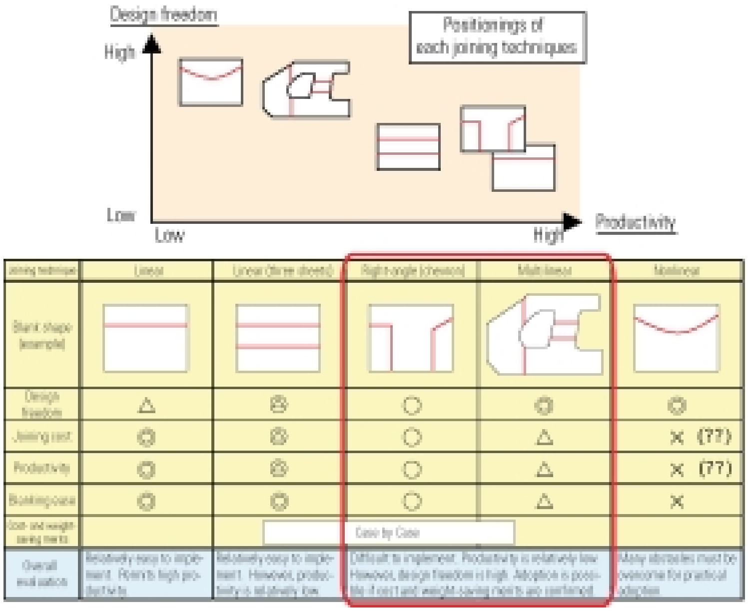

Fig. 3 Joining techniques for tailored blanks

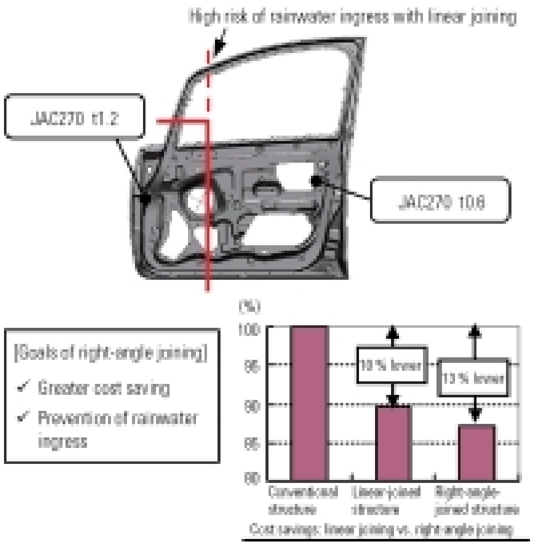

Fig. 4 COLT front door inner panel (right-angle joining)

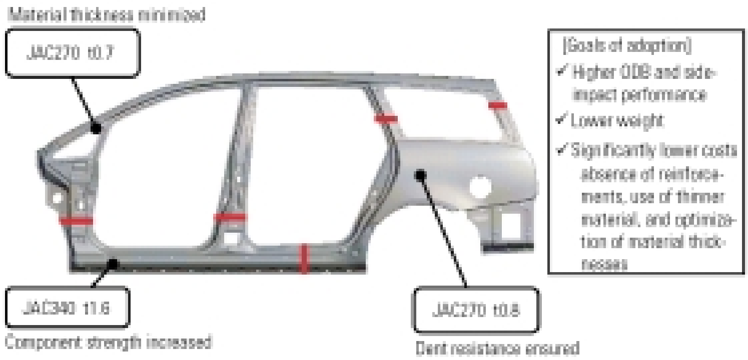

Fig. 5 GRANDIS side outer panel (multilinear joining)

tion of rainwater ingress past the door seals, which is a hurdle with the linear joining, and realizing a greater cost saving than was possible with the linear joining technique (**Fig. 4**). And with the side outer panels of the GRANDIS (the most challenging body panels with respect to application of tailored blanks), MMC adopted the multilinear joining technique, thereby achieving superior strength in the side sills and concomitantly superior collision performance while keeping the accompanying weight increase to a minimum (**Fig. 5**). The multilinear joining technique contributed to a 6☆ crashworthiness rating (the highest available rating) for the GRANDIS in the Japan New Car Assessment Program. And given that the door inner panels are relatively large components, the multilinear joining technique yielded a concomitantly great saving in material costs. Specifically, the cost saving was 2.7 times the cost saving that was yielded by adoption of the right-angle joining technique with the door inner panels of the COLT.

3. Technological hurdles overcome

Examples of technological development accomplished by MMC are described hereafter.

3.1 Repression of butt gaps between sheets

In laser butt welding, a laser beam with high energy density is applied to the abutting edges of the pieces of material, causing them to melt and fuse together. If there is a gap of 0.2 mm or more between the pieces of material, the welded material is insufficient, resulting in a defective joint.

With multilinear joining, the joints are made at multiple locations in two directions, so preventing unwanted gaps is more difficult than it is with linear joining.

Unwanted gaps can be caused by insufficient precision in the cut faces of the pieces of material and by insufficient precision in the positioning of the pieces of material (**Fig. 6**). As shown in **Fig. 7**, MMC focused on four aspects (including the butting sequence and material-pushing positions) of the positioning process. If, for example, the pushing positions are poor, a butt gap can occur in a certain location. And if the pushing-together forces are not well balanced, the pieces of material may not move as intended. MMC used a test jig to optimize the relevant attributes and reflected the results in production jigs.

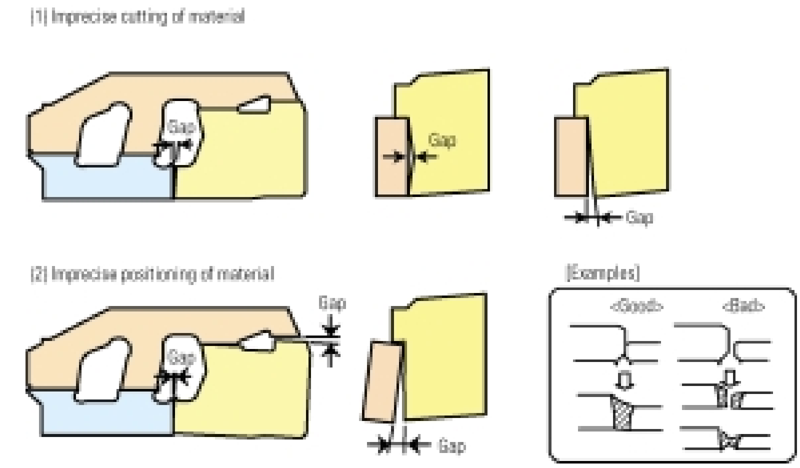

Fig. 6 Causes of material butt gaps

3.2 Optimization of laser-welding conditions

Even if the cutting and positioning of the pieces of material are achieved with high precision, it is conceivable that variation will be caused by various factors under production conditions. Measures to deal with such variation were particularly necessary with multilinear joining. MMC deemed that the ideal welding conditions were those permitting wide ranges of tolerance with respect to variation and enabling rapid welding process.

Fig. 8 is an example of a weld cross-section matrix in which the size of the butt gap is shown against the horizontal axis and the application position of the laser beam is shown against the vertical axis. The ringed areas correspond to defective conditions in which the required weld strength standard is not satisfied, and the central, boxed area corresponds to the range of tolerance with respect to variation. MMC gathered weld-test data in line with the principle reflected in **Fig. 8** and used them to establish welding conditions that permitted the highest possible speed and a wide tolerance range. These measures realized stable production with a low defect rate.

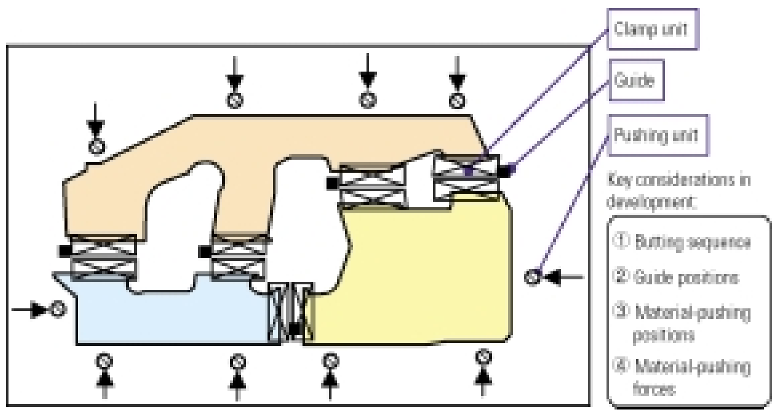

Fig. 7 Material positioning jig (outline)

3.3 Quality assurance

Establishing a quality-assurance process was the most crucial technological issue for precluding the need for preventing defective products from reaching post-processing and marketplace.

First, quality standards were established by means of sampling tests and pressing-limit verification tests (**Fig. 9**). To guarantee satisfaction of these standards, quality check gates were established in the material-cutting process, welding process, and pressing process and used to ensure satisfaction of criteria related to weld strength, material perforation, and joint height differences (**Fig. 10**).

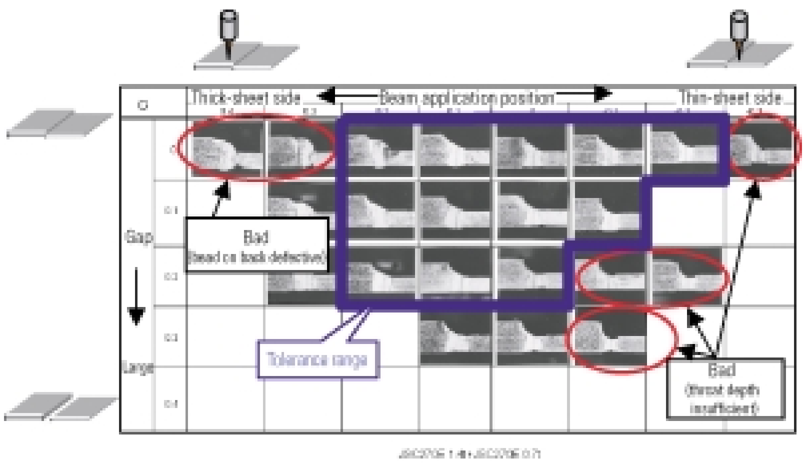

Fig. 8 Tolerance range for positional variation during welding

In addition, two quality monitoring system were incorporated into the welding process. This device checks each weld bead precisely and feeds out to a separate stage any product that it deems defective (**Fig. 11**).

To further ensure quality, products are sampled at random and subjected to destructive testing and visual inspections.

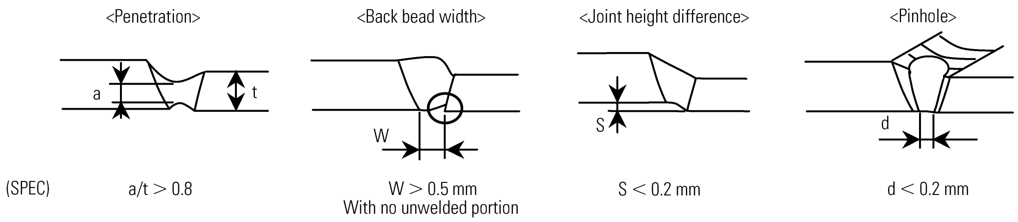

Fig. 9 Tailored blank quality standards

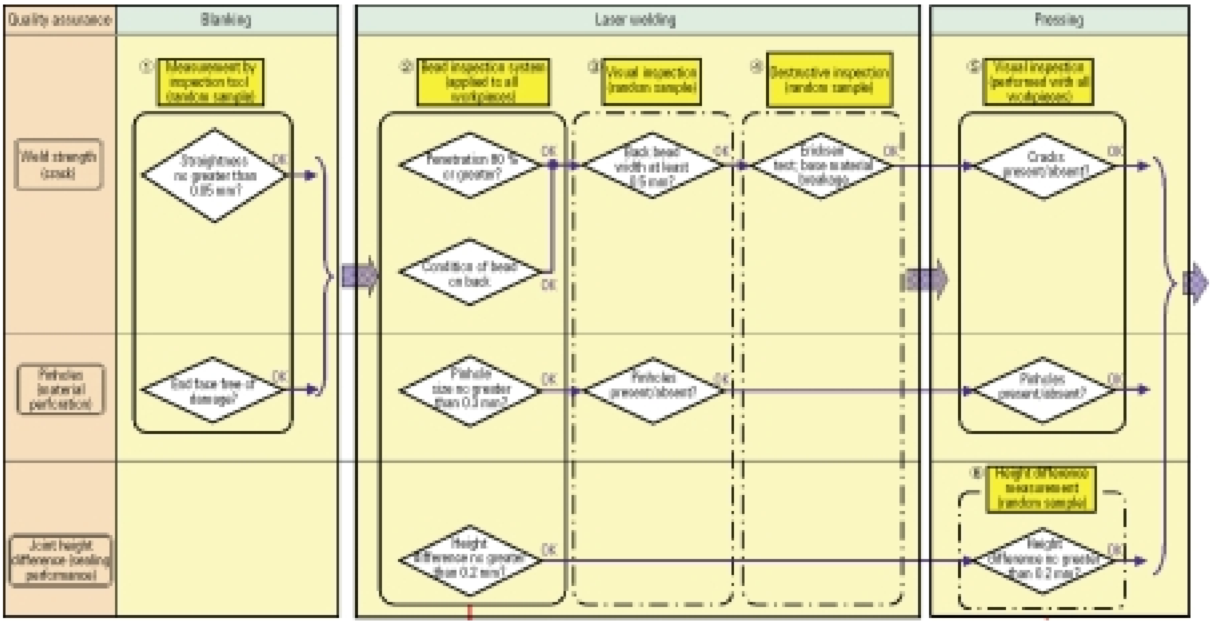

Fig. 10 Quality assurance system

3.4 Adoption of flexible laser-welding system

Given the widely different joining arrangements and product sizes of the COLT and GRANDIS, MMC created a highly flexible welding system by

(1) adopting an interchangeable-jig arrangement;
(2) establishing a wide operating range for the laser head; and
(3) adopting a high-output laser diode-pumped YAG laser.

As a result, the system can perform linear, right-angle, and multilinear joining and can accommodate products ranging from those of medium size to those that are large (for example, side outer panels).

With vehicle models developed in the future, MMC will be able to make the system usable by simply modifying and/or newly producing positioning jigs in accordance with welding requirements. MMC will be thus able to prepare for production of new models with a minimum of capital investment.

The system's major specifications are shown in **Table 1**.

4. Summary

MMC developed the necessary fundamental technologies and a flexible welding system for adoption of

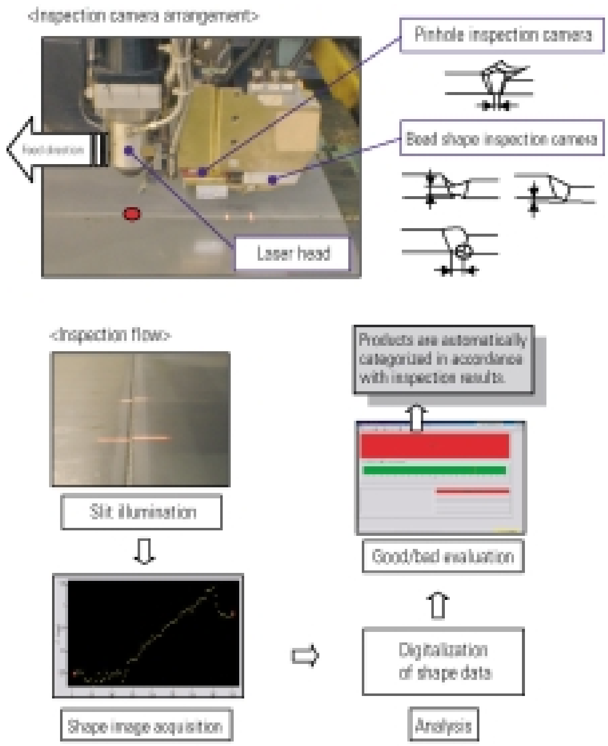

Fig. 11 Quality monitoring system

Table 1 Major specifications of laser-welding system

Item	Specification	Remarks
Laser oscillator	4.0 kW laser diode-pumped YAG laser	
Laser processing equipment	4-axis open-side NC machine X-axis: 5,000 mm Z-axis: 350 mm Y-axis: 1,200 mm C-axis: ±90˚	
Possible joint types	Linear, right-angle, multilinear	Interchangeable jig type
Weld length	Linear: max. 1,800 mm Multilinear: max. 5,000 mm x 1,200 mm	

tailored blanks made using right-angle and multilinear joining techniques for the COLT and GRANDIS. Having established a production system, MMC began mass production of the tailored blanks in October 2002 and has since continued to produce them on a stable basis.

MMC's application of a multilinear joining technique to large outer panels was a world first. The company aims to expand its application of this unique technological asset to other vehicle models.

5. Acknowledgements

Production of multilinear-joined tailored blanks was made possible not only by body- and production-engineering-related development work but also by extensive cooperation from factory personnel. The authors wish to express sincere gratitude to everyone involved.

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MITSUBISHI AUTO GALLERY

— Vehicles Which Mark An Era —

MIRAGE 1400 GLX (1978)

The MIRAGE 1400 GLX reflected contemporary concerns about limited resources. Based on a policy of making effective use of limited space and prioritizing functionality, it was developed to be a worldwide car combining a compact exterior form with ample seating space, innovative mechanicals, and comprehensive refinement.

Practical Tolerance Analysis Simulation

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Abstract

In the past, the cumulative tolerance at the development stage for parts assembled together was verified by manual root extraction from the sum of squares in a two-dimensional drawing. Generally, however, the parts of a motor vehicle have a complicated structure, and the variance in three-dimensional space cannot be accurately estimated by the conventional calculation procedure.

Therefore, a project for improving the quality of mass-produced vehicles was established. The project is characterized by arithmetic estimation of the cumulative tolerance in three-dimensional space and prediction of likely defects. This paper outlines our practical tolerance analysis simulation using a three-dimensional CATIA model and its application for developing the COLT PLUS.

Key words: *Tolerance, Simulation, CATIA, Process Capability*

1. Introduction

An automobile is made up of numerous parts, and the manufacture of those parts inevitably involves variations in size. A tolerance is a range of variance specified at the designing stage, but the cumulative sum of tolerances for individual parts may result in gaps, misalignment, faulty assembling, malfunction of moving sections, etc. The aim of tolerance analysis simulation is to clarify the requirements that must be satisfied in order to ensure the required quality of the finished vehicle by calculating the cumulative tolerance for it.

2. Background for introduction of tolerance analysis system

In the past, the cumulative tolerance was manually calculated by root extraction from the sum of squares on a two-dimensional plane (**Fig. 1**), which made three-dimensional positions and revolution hard to analyze. To solve the problem, we decided to introduce a system (3DCS by Dimensional Control Systems) for simulating the cumulative tolerance in three-dimensional space. We also tried to establish a parts installation standard and a positioning method necessary for a three-dimensional product model, which is indispensable for tolerance analysis. We also upgraded drawings so that shape tolerance information could be incorporated.

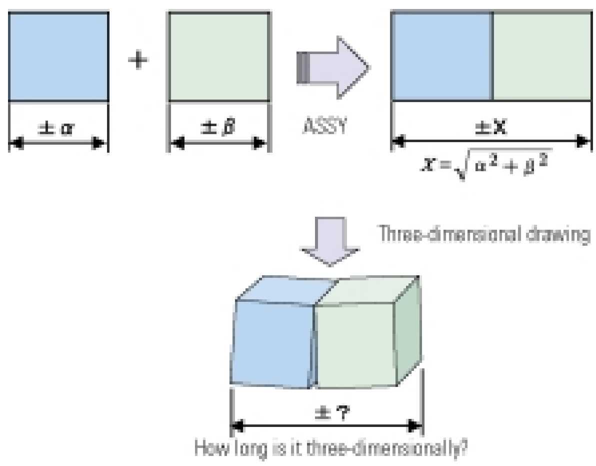

Fig. 1 Problems with analysis of three-dimensional model

3. Tolerance analysis procedure

3.1 Analyzed stages and analysis points

The tolerance analysis starts upon starting to design a vehicle and ends when the model is established. The problems detected on the present model and important sections of a new structure were analyzed. The basic coverage is shown in **Table 1**.

In addition, the analysis was conducted for previously developed components and faulty sections of mass-produced vehicles.

3.2 Tolerance simulation process

3.2.1 Preparation of necessary information

The overall flow of tolerance analysis work is shown in **Fig. 2**.

The following information should be prepared:

CAD models of the component parts necessary for the analysis, information on their tolerance, methods of positioning by using a jig or tool, positioning accuracies, assembling procedures, general manufacture tolerances not specified in drawings and the final required accuracies of the sections to be analyzed. If there is a

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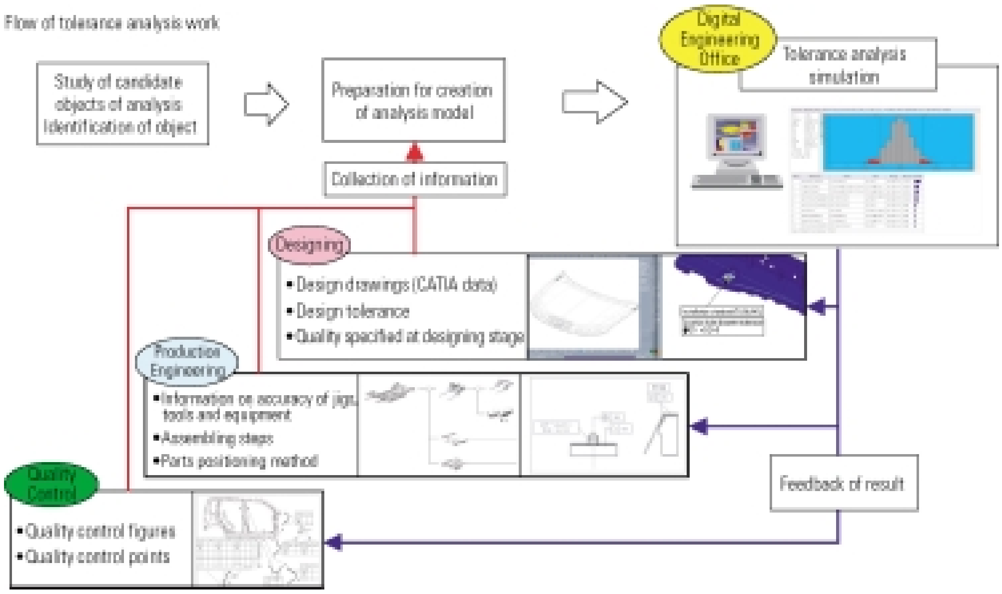


Fig. 2 Tolerance analysis process

Table 1 Examination items and analysis points

Examination Items	• Whether the part is properly installed or not • Whether the fitting meets the appearance criterion or not • Rate of non-conformance to the required specifications • Contribution by specified tolerance/positions
Analysis points	• Installation of front and rear suspensions • Installation of fuel tank • Front and rear exterior • Installation of glasses • Front and rear doors • Installation of steering column • Installation of front and rear sheets

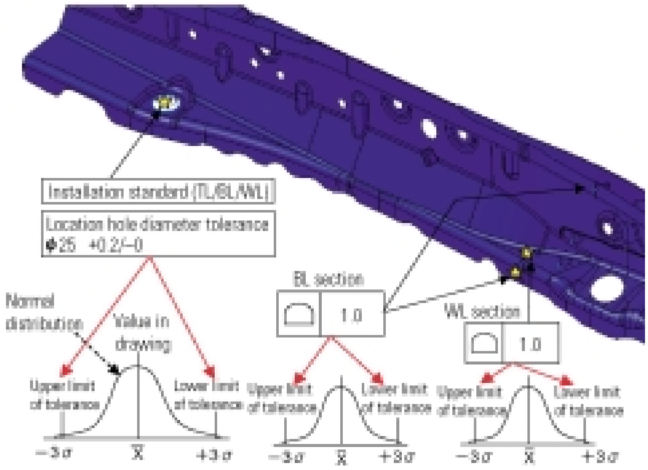


Fig. 3 Tolerance information input

vehicle similar in structure to the one being analyzed, production variance information for the present model as well as the design tolerance may be used.

3.2.2 Creation of tolerance simulation model

Binding-related information was defined for the CAD models for parts based on the tolerance information. A surface tolerance value was specified for both of the surfaces to be joined, and position, diameter and tightening surface accuracies were specified for tightening holes. If binding with a jig was necessary, locater surface accuracy for the jig, position accuracy for the location pin and information on pin diameter tolerance were added (**Fig. 3**). These prerequisite conditions specified are important since the analysis results depend heavily on them.

3.2.3 Tolerance simulation

Variances were generated on the basis of the normal distribution probability with upper and lower limits equal to the tolerance values specified at the time particular values were specified for the parts models. Because of this, all values specified for the CAD models randomly deviated from the reference every time a calculation was made. Such a combination of parts evolved into a finished-product model involving the positional variance of parts.

The distances to and the angles of evaluation points were measured. Typical calculations are presented in **Figs. 4** and **5**.

The variance involved in measurements taken 10 to 1,000 times provides a distribution pattern, which can be compared with the accuracy demanded for a finished product (**Figs. 6** and **7**). The specified elements can be listed in the order of contribution to the pertinent section subjected to measurement (**Table 2**).

Due to this, parts of complicated shape can be analyzed three-dimensionally, and information not obtained in the past such as variance distribution, spec-

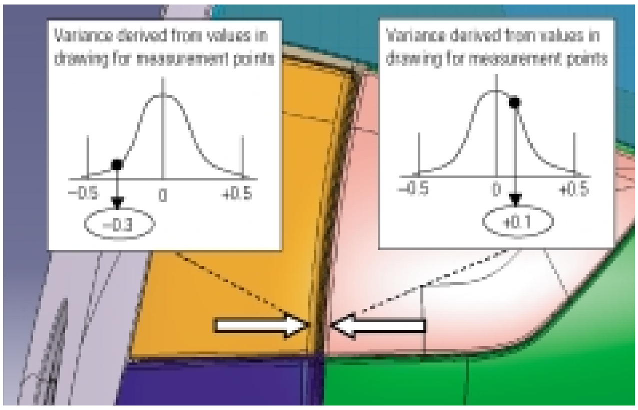


Fig. 4　Gap measurement

out rate and the contributions of elements of variance can be identified visually.

3.3　Result of analysis and planning for countermeasures

If the distribution (expected variance) of the section evaluated in **Fig. 7** was narrower than the required accuracy range (from the lower limit to the upper limit), the design was judged acceptable. If wider, those factors judged to be responsible were identified according to the contributions (**Table 2**) and analyzed, and countermeasures were planned, while noting the following aspects:

Review of the structure and the specified tolerance, review of the parts positioning method and the assembling procedure, proposal of an adjustment-making structure, improvement of the accuracy of individual parts, review of the accuracy control range for sub-assembly, review of the preferential control points, etc. Simulation is performed again based on the new tolerance and control values, and the effect of the action is checked. If the requirements are satisfied, the tolerance values in the drawing and the equipment are adjusted accordingly.

4.　Typical applications

4.1　Vehicle height analysis for COLT PLUS

A study was undertaken to find out a way to provide a vehicle height that does not exceed the limit and can be accommodated in a multilevel parking garage, in compliance with a request, and a measure was taken to provide such a vehicle height actually. As wide variance of vehicle height was foreseen for COLT PLUS at the designing stage, the actual height variance of finished vehicles was verified by tolerance analysis as part of the study at the vehicle development stage.

4.2　Result of analysis

Fig. 8 presents a model in which tolerance values are incorporated after parts causing vehicle height variance of the COLT PLUS are identified at the verification stage. The lightest and heaviest models (the weight depends on the combination of options) were prepared.

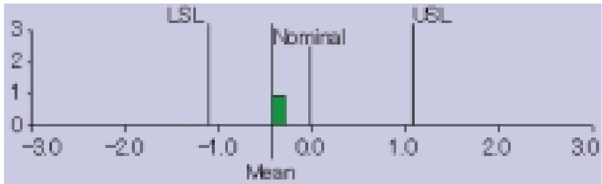


Fig. 5　Measurements (first)

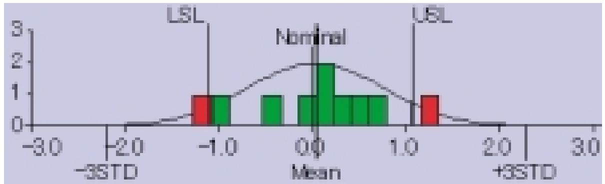


Fig. 6　Measurements – cumulative (tenth)

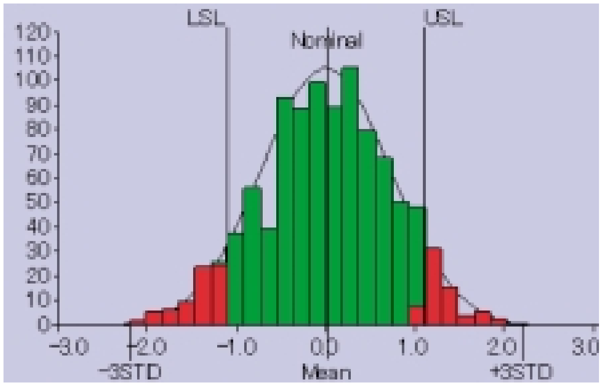


Fig. 7　Measurements – cumulative (thousandth)

Table 2　Degrees of contribution

Index	Tolerance	Point	Part	Percent	Graph
1	Profile_Spring_LH	5(Group)	RR_SUS_2WD_1	[illegible] %	
2	Profile_Roof	CENTER(Group)	BODY_2WD_1	[illegible] %	
3	Linear_Spring_LH	2(Group)	FR_SUS_1	7.23 %	
4	Profile_Sp_Body	1_SP_RH(Group)	BODY_2WD_1	4.29 %	
5	TORSION_ARM_TO_HUB	TA_HUB_RH	RR_SUS_2WD_1	3.76 %	
6	Linear_Spring_RH	2(Group)	FR_SUS_1	2.59 %	
7	[illegible]	1(Group)	RR_SUS_2WD_1	[illegible] %	
8	[illegible]	[illegible]	BODY_2WD_1	1.59 %	
9	Profile_Upper_Spring_Pad_LH	6(Group)	RR_SUS_2WD_1	1.34 %	
10	Profile_Lower_Spring_Pad_LH	[illegible]	RR_SUS_2WD_1	1.34 %	
[illegible]					

Weight variance was converted into figures representing spring length.

The combination of options which gives the minimum weight and maximum height resulted in the specified value being exceeded (**Fig. 9**). By analyzing the degrees of contribution, we ascertained that the manufacture variance of the length of the spring for the suspension is a major factor and that the vehicle height can be brought to the specified level by changing the spring

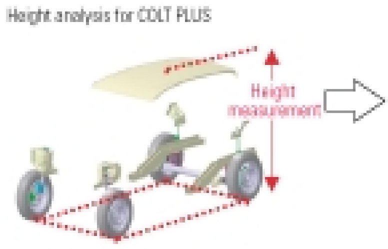


Fig. 8 **Creation of analytical model**

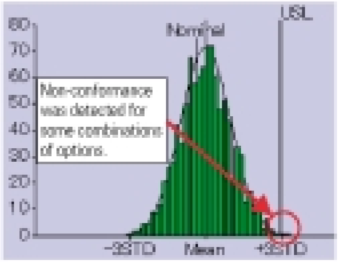
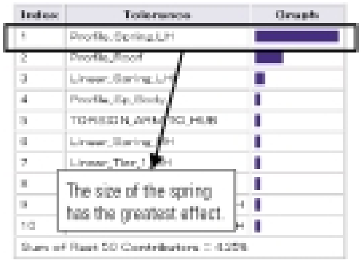


Fig. 9 **Result of analysis**

Table 3 Determination of degrees of contribution



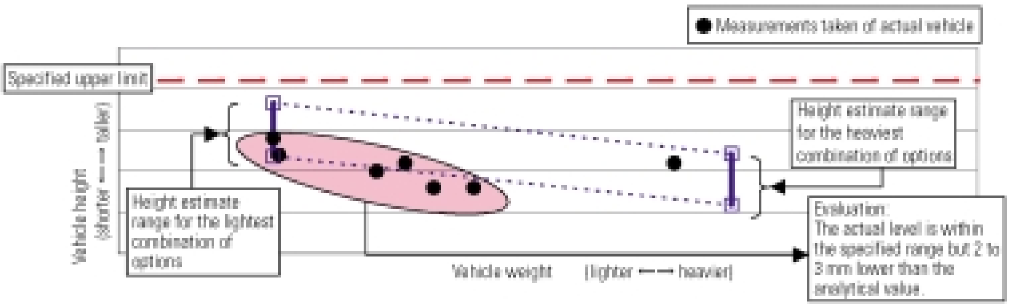


Fig. 10 Comparison of analytical and actual figures (relationship between vehicle hight and vehicle weight)

length appropriately. Therefore, we judged this change as a countermeasure (**Table 3**).

By comparing the results of the analysis and actual measurements, we found that the vehicles examined did not exceed the upper limit and that the analysis results closely agreed with the reality (**Fig. 10**). The height is measured on the inspection line for mass-produced vehicles, and appropriate action is taken to detect non-conformances without fail on that line.

5. Remaining tasks

There is a demand for analytical output closer to the actual variance range. To improve the analytical accuracy, we hope to verify agreement between the simulation results and the reality, and to prevent or eliminate problems attributable to the restrictions in analysis software (limited number of points at which parts are fixed together, inability to determine distortion and deformation because the model is calculated as rigid, etc.).

6. Conclusion

We wish to ensure the production process capability by reflecting the necessary and sufficient conditions, thus enabling accuracy verification factors to satisfy the design specifications, to the design drawings and production preparations. We will also work to stabilize product quality.

Finally, we sincerely thank those concerned inside and outside the Company for their assistance.

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“e-DES”, the DfE (Design for Environment) Promotion Management System by MMC

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1. Foreword

In product development and designing, efforts based on Design for Environment (DfE), i.e., the concept of designing with consideration given to the environment, are required.

DfE means development and designing to reduce the environmental load throughout the product lifecycle starting from mining of raw materials, and the system to manage such efforts.

This paper introduces the management system “environmental Design & Evaluation System (e-DES)” for considering the environment during development and designing MMC (Mitsubishi Motors Corporation) plans to apply at an early stage.

2. Efforts for environmental protection at MMC

First, the positioning of the DfE promotion in the entire-company environmental protection is introduced.

Efforts for environment protection at MMC are based on the “Environmental Guidelines of MITSUBISHI MOTORS CORPORATION” issued in FY1999 (**Fig. 1**). This guideline declares that MMC will make continuous, proactive endeavors for environmental protection in both management and performance. DfE means achieving this in development and designing.

The organizational structure is shown in **Fig. 2**, with DfE led by the DfE Promotion Working Group.

MMC announced the “Environmental Sustainability Plan” in FY2002 (**Table 1**). This is a summary of the environment-related projects of MMC with a target deadline of around five years. The DfE is positioned inside the environmental management area and MMC has established a target and is promoting the plan.

3. DfE promotion management system “e-DES”

Next, specific DfE promotion activities are introduced.

MMC plans to apply a unique management system for DfE, “e-DES”. The name e-DES is derived from a series of processes (management system) from designs for environment to their evaluation.

The e-DES provides the specific standards, procedures and system for promoting environmental consideration in the development and designing processes.

MMC ENVIRONMENTAL GUIDELINES

Basic Policy

MMC recognize that protection of the global environment is a priority for humankind and as such makes the following pledge:

(1) From a global viewpoint, we are committed to continual reduction of negative environmental impact of our corporate activities with all our strength, these including development, procurement, production, sales, and after-sale servicing activities related to automobiles.

(2) As a good corporate citizen, we are committed to action to protect the environment at the level of local communities and society as a whole.

Behavioral Standards

(1) We will endeavor to protect the environment by forecasting and assessing the environmental impact of our products at all stages in their life cycle.
Priority is given to the following areas:
- Prevention of global warming by reducing emissions of greenhouse gases
- Prevention of pollution by restricting emissions of substances harmful to the environment
- Reduction of waste and maximizing efficient use of resources by promoting conservation of resources and recycling

(2) We will endeavor to improve our environment management practices as part of ongoing efforts to ameliorate the environment.

(3) We will comply with environment regulations and agreements, and will work to protect the environment by establishing voluntary management targets.

(4) We will encourage our affiliates and suppliers, both in Japan and overseas, to cooperate in working to protect the environment.

(5) We will actively disclose environment-related information and will seek the understanding of local communities and of society at large.

Issued in August 1999

Fig. 1 Environmental guidelines of MITSUBISHI MOTORS CORPORATION

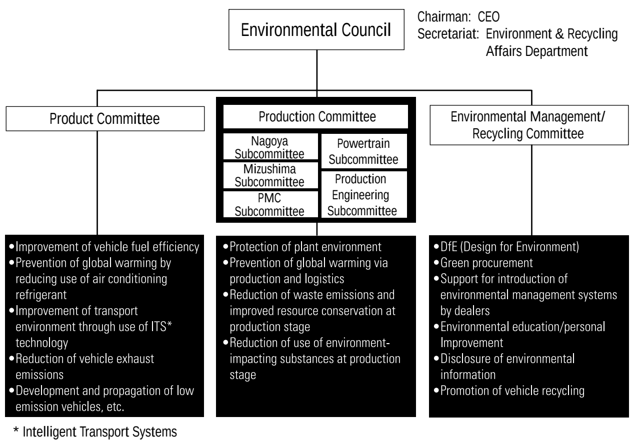


Fig. 2 Organizational structure

* Environment & Recycling Affairs Dept., Group Corporate Strategy Office

Table 1 Environmental Sustainability Plan (listed items only, as of March 2003)

(1) Environmental management

Category	Item
Design for Environment (DfE)	Application of DfE
Cooperation with suppliers (green procurement)	Promotion of acquisition of ISO 14001 certification
Cooperation with dealers	Support for introduction of environmental management systems by dealers
Collaboration with domestic and overseas production affiliates	Promotion of acquisition of ISO 14001 certification Cooperation with domestic production affiliates Cooperation with overseas production affiliates
Disclosure	Disclosure of environmental information

(2) Recycling

Category	Item
Promotion of vehicle recycling	Compliance with Japanese and EU legislation on vehicle recycling/improvement of recyclability/reduction of use of environment-impacting substances
Reduction of waste emissions and improved resource conservation at production stage	Zero emissions of landfill waste Promotion of recycling Reduction of emissions of byproducts Effective use of water resources

(3) Prevention of global warming

Category	Item
Improvement of vehicle fuel economy	Compliance with new domestic fuel economy standards Attainment of self-targets for EU fuel economy
Reduction of use of air conditioner refrigerant	Reduction of use of HFC134a Promotion of development HFC134a-free air conditioners
Production and logistics	Reduction of emissions of CO_2 (energy conservation at plants) Reduction of CO_2 emissions at logistics stage Reduction of packaging and packing materials
Improvement of traffic flow	Improvement of transport environment through use of ITS technology

(4) Prevention of environmental pollution

Category	Item
Development and propagation of low emission vehicles,etc.	Promotion of R&D on fuel cell vehicles (FCVs) Market launch of clean energy vehicles Expansion of vehicles achieving both high fuel economy and low emission Compliance with Japanese and overseas exhaust emission regulations
Reduction of use of environment-impacting substances at production stage	Reduction of VOC emissions Reduction of dioxin emissions

At all stages of the product lifecycle:
- Prevention of global warming
- Prevention of environmental pollution
- Controlling resource consumption and waste generation

Fig. 3 Priority areas of e-DES

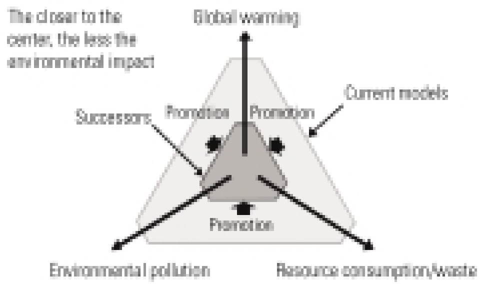


Fig. 4 Image of DfE promotion through e-DES

The objectives are as follows:
- Continuous improvement of the environmental performance throughout the lifecycle of the products
- Continuous improvement of the environmental management in development and designing of the products
- Communication concerning the above both inside and outside the company

Three key areas to be addressed concerning the environmental effects of automobiles are defined as shown in **Fig. 3**. The communication above concerns the policies and attitudes in development and designing of MMC’s products and is not intended for comparisons or claims with competitors.

Procedures of the e-DES are shown below.
- The projects shall be controlled by the “quality gate (QG)” in MMDS*.
- The personnel in charge of management of development shall be appointed a leader for each project, who shall organize the DfE team of the staff in the Designing and Quantification Departments and promote their activities.
- The progress of each project shall be improved and reviewed.
- The targets shall be decided and evaluated from the early stage of development for the physical quantities (environmental indexes) involved in the priority areas.
- The index in consideration to the environment based on MMC’s original concept shall be applied and the goal shall be set to exceed the current models in the market (**Fig. 4**).
- The environmental information of the products shall be collected and arranged in order.

*MMDS: A management tool unique to MMC for new model development projects defines the major management points in the development process as “quality gate (QG)” and stipulates other specific procedures and systems.

Fig. 5 shows the execution system and **Fig. 6** shows the process. The department in charge of designing provides the results of the designing reviews. The department in charge of quantification quantifies the results. The personnel in charge of management of the development and designing takes the leadership in the promotion, and evaluates, judges and reports the degree of achievement of the targets.

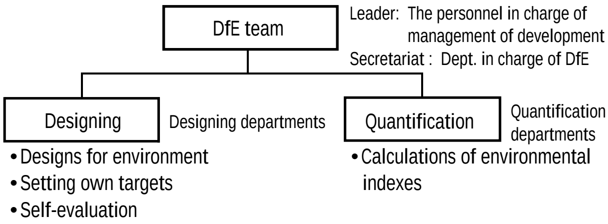


Fig. 5 Execution system for e-DES

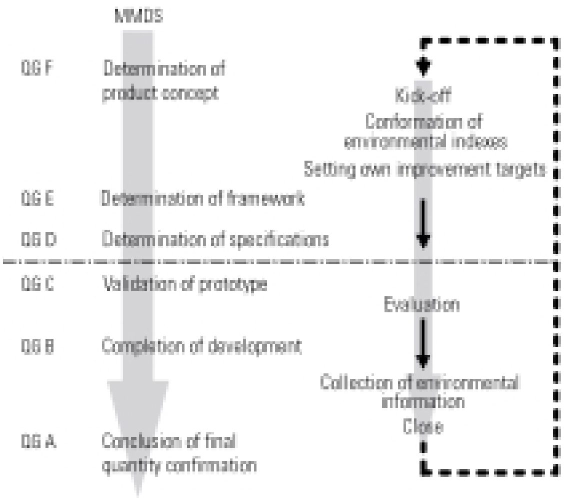


Fig. 6 Process of e-DES

The DfE Promotion Working Group provides overall support. Top management passes judgment on the major management points according to conformity of MMDS.

Table 2 shows the environmental indexes for the priority areas.

As described above, the system comprehensively allows steady environmental measures as a model changes.

4. Utilization of LCA

Life Cycle Assessment (LCA) is a method for quantitatively assessing the load to the environment, resource consumption and accompanying environmental impact caused by discharge of a product during its lifecycle in order to achieve the target function, and for interpreting the results in accordance with the research objectives.

MMC positions LCA as an evaluation tool for the DfE and uses the total amount of lifecycle CO_2 discharge obtained by LCA for the evaluation physical quantity for prevention of global warming.

The following is the calculation method at the manufacturing stage in LCA of MMC. The calculations are based on research by the Japan Automobile Manufacturers Association, and the scope ranges from mining resources to manufacturing of vehicles.

A list of weights per part and material for LCA calculations is created from the vehicle designing data and

Table 2 Environmental indexes of e-DES

Priority area	Environmental indexes	Relationship to the life stage		
		Production	Usage	Disposal
Prevention of global warming	LCA value (CO_2)	√	√	√
Prevention of environmental pollution	Emission gas		√	
	Amount of hazardous substance			√
Controlling resource consumption and waste generation	ASR weight			√
	Vehicle weight	√		
	Fuel efficiency (10·15 mode)		√	
	3R (Reduce, Reuse, Recycle) index	√	√	√

Table 3 Classification of parts in LCA calculations (partial)

Unit: kg

Sub-classification	Part name	Model A	Model B
M2****	WHEEL & TIRE	39.4	51.2
M5****	REAR SIDE STRUCTURE	46.6	60.9
M5****	FENDER SHIELD	18.9	42.5
M5****	REAR FLOOR	29.4	28.5
M6****	FRONT SEAT ASSY	33.3	30.4
M1****	CYLINDER BLOCK	22.3	31.4

Table 4 Classification of materials in LCA calculations (partial)

Material name	Material code
Structural steel	31
Structural alloy steel	32
Thermo plastic elastomer	77
Polyamide	78
Aluminum alloy sheet	53
Wire	23

the working processes are specified from the results to calculate the quantity of CO_2 discharge.

The minimum structures of parts are categorized as shown in **Table 3**. There are about 500 categories. The materials are categorized as shown in **Table 4** and there are around 80 categories.

The designing data are reorganized into a list for LCA calculations as it is not realistic to calculate for each of the 20,000 to 30,000 parts.

The working processes are defined according to the materials (**Table 5**).

For calculation of the CO_2 discharge quantity, the data on the CO_2 discharge quantity in the principle unit (per unit weight) for each working process is obtained from the MMC plants in advance, and the quantity is calculated through integration with the material weights.

For outsourced parts, MMC uses published data and document data at present.

Table 5 Working processes in LCA calculations (partial)

Material name	Material code	Working process	Working process code
Cast iron	1	Casting + cast iron machining	P1 + P6
Cold-rolled steel sheet	11	Pressing	P3 or P4
ABS (Acrylonitrile, Butadiene, Styrene)	75	Resin molding	P10
Hot-rolled steel sheet	12	Pressing	P3 or P4
Steel billet	21	Forging + steel machining	P5 + P7

5. Management of hazardous substances

In Europe, the use of four substances (lead, mercury, cadmium and hexavalent chromium) is banned by EU directive on end-of-life vehicle. In Japan, the Japan Automobile Manufacturers Association voluntarily established targets for reduction of the above four substances. Requirements for management of materials that cause environmental load are growing both inside and outside Japan. MMC is therefore promoting efforts to comply with those requirements.

MMC currently collects data on 89 substances contained in parts and materials as those that cause environmental load through the International Material Data System (IMDS) from suppliers, collects and analyzes the data using the in-house system to understand the actual conditions and confirm compliance with the regulations.

The data obtained here is used in calculations for the ASR weight and the amount of hazardous substances that are the environmental indexes of the e-DES.

MMC will extend this system to accommodate for part of the functions of e-DES in the future and efficiently manage substances that cause environmental load.

6. Postscript

This paper introduced the efforts on environmental consideration in development and designing at MMC. MMC plans to accumulate the LCA data in all priority areas, utilize the data and steadily manufacture automobiles with consideration of the environment. Although there is some uncertainty as to whether these efforts will be accepted in society and the market, they reflect the social trends, and we hope they will contribute to society and enhance MMC’s value.

Hisao MORI

Takashi ISOGAI

Eizo TABO

New Paint Shop at Mizushima Plant

Yoichi KOYAMA*

1. Introduction

In August 2004, Mitsubishi Motors Corporation (MMC) began operating a newly constructed passenger-car paint line at its Mizushima plant. The new paint shop, which replaced an existing one and incorporates state-of-the-art technologies, has a design based on the findings of research that encompassed facilities operated by DaimlerChrysler and other overseas automakers and the latest technological trends among facilities suppliers and paint suppliers. An overview of the new paint shop is given in this paper.

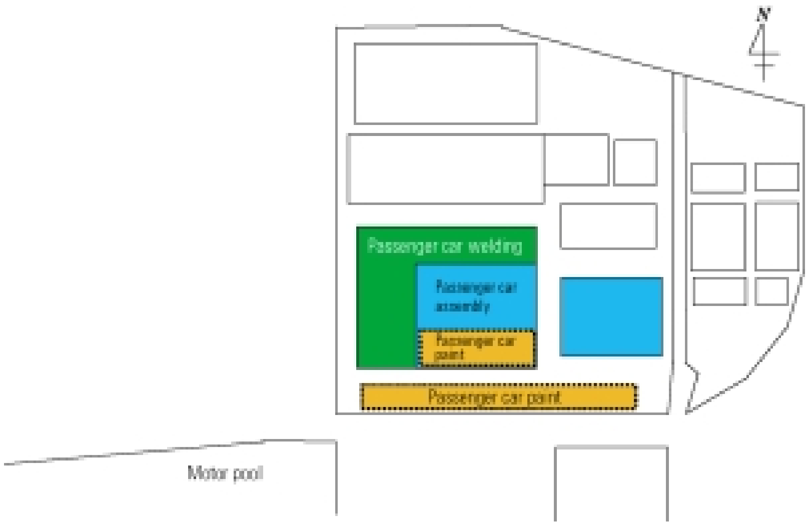


Fig. 1 Mizushima plant layout (old)

2. Background and view of construction

The old paint shop was built in 1979 and had deteriorated through long use. Notwithstanding partial refurbishment of its facilities, significant expenditure was necessary to maintain adequate quality and production volume. Also, advances made in the safety and interior spaciousness of passenger cars mean that the body frames of today's passenger cars have weights and dimensions greatly exceeding those that were factored into the facilities design of the old paint shop; the old paint shop was extremely problematic with respect to introduction of new vehicle models. Further, MMC needed new painting facilities for success in its effort to cut emissions of environmentally harmful Volatile Organic Compounds (VOC).

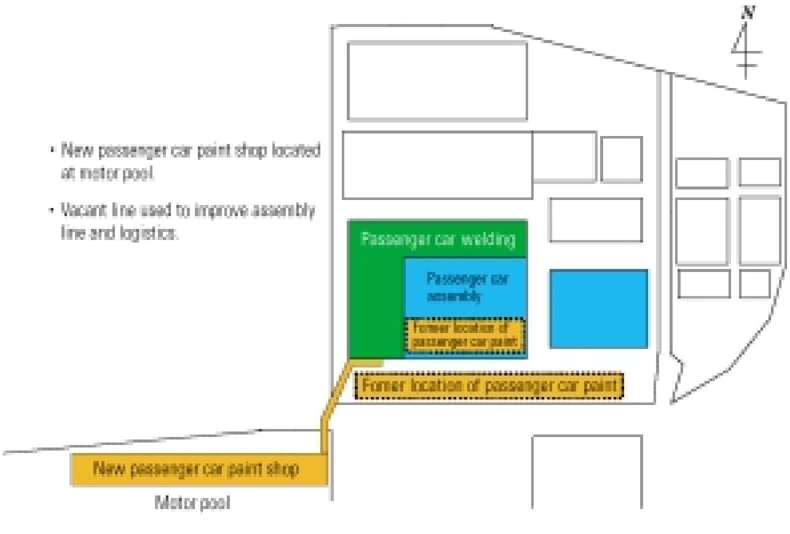


Fig. 2 Mizushima plant layout (new)

Meanwhile, MMC's turnaround plan called for urgent reorganization and improvement of the entire Mizushima plant (MMC's main manufacturing base). Tearing down the old paint shop and building a new one gave MMC an opportunity to increase quality and cut costs in painting processes and to use the space made available by the old paint shop's removal to improve logistics and movement of parts within the Mizushima plant (**Figs. 1** and **2**). Plus, building the new paint shop enabled MMC to take the environmentally responsible step of adopting waterborne paint (with very little organic solvent in the filler and top coat) to reduce VOC emissions.

3. Basic layout

The new paint shop occupies a three-floor, steel-framed building (the basic layout of its first and second floors is shown in **Fig. 3**).

* Production Engineering Paint Dept., Production & Logistics Office

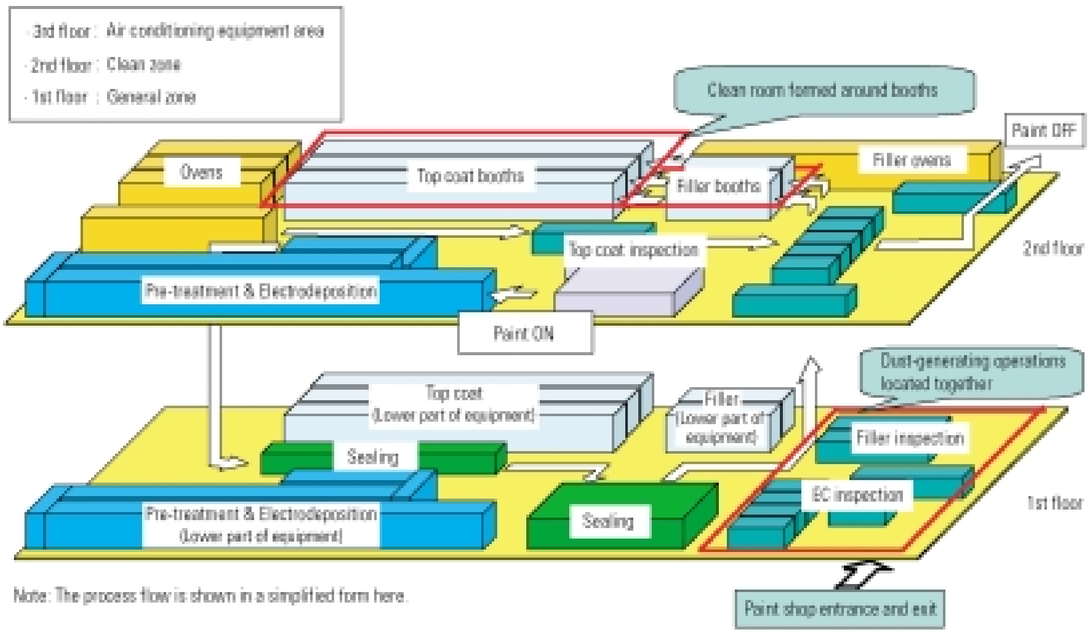


Fig. 3 Layout

To prevent contamination of paint layers by dust and dirt (this is the most common cause of paint defects), the building is divided into zones with different levels of cleanliness. The first floor is a general zone. The operations that generate the most dust (inspection and sanding) are located on the first floor. The second floor is a clean zone. The filler booths and top-coat booths, which demand cleanliness, are located on the second floor. To keep dust and dirt out of the filler booths and top-coat booths, the area surrounding these booths is enclosed within walls that double as fire partitions.

The paint shop accounts for approximately 60 % of the vehicle manufacturing plant's energy usage. To promote energy conservation, the ovens and pre-treatment process, which generate heat, are located together as far as possible from processes in which people are engaged.

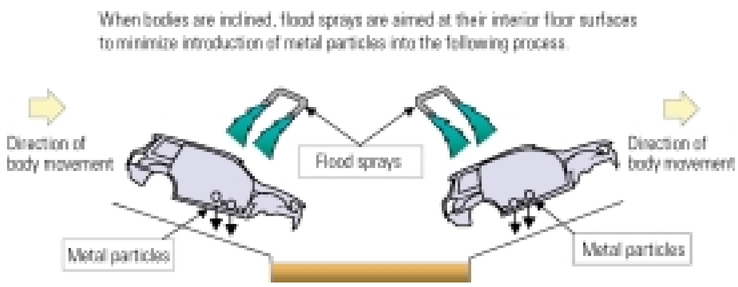


Fig. 4 Improved washing of interiors of vehicle bodies

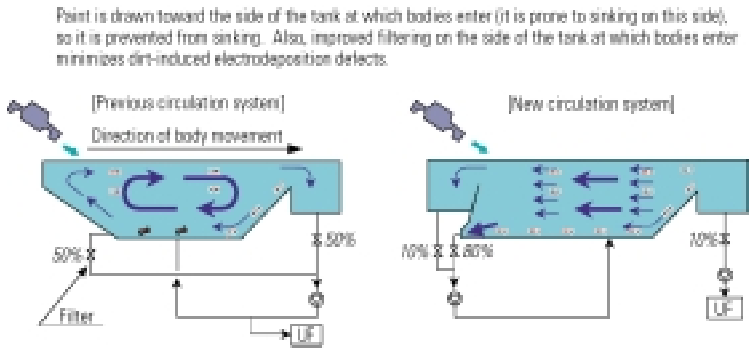


Fig. 5 New circulation system for electrodeposition tanks

4. Major technologies

4.1 Pre-treatment and electrodeposition

The pre-treatment and electrodeposition process is crucial since it produces a substrate that performs a rust-preventing purpose and forms the foundation for attractive paintwork. Extensive measures taken there for quality enhancement are focused on prevention of dirt-related defects. Major quality-enhancing measures are as follows:

(1) To prevent introduction of metal particles from the welding shop, which precedes the pre-treatment process, the interiors of vehicle bodies are washed with increased thoroughness (**Fig. 4**).
(2) A new circulation system in the electrodeposition tanks realizes more thorough removal of dirt from the electrodeposition system (**Fig. 5**).
(3) Water-draining dolphin transportation and pre-heating prevent EC sagging.
(4) An improved body transportation system minimizes falling dirt.

Further, full-swinging hangers and a float-type arrangement for preventing body flotation were adopted, making the process shorter.

4.2 Sealing

The sealant and undercoat must be applied properly since they are crucial with respect to water leakage and rust resistance. The processes were more than 90 % automated in the old paint shop. For even more consistent quality, two new technologies (described below) were adopted in the new paint shop.

(1) Cameras are used to check body positions, and the sealing robots' operating positions are automatically adjusted accordingly (**Fig. 6**).

(2) Swirl-type spray guns enable uniform application (**Fig, 7**).

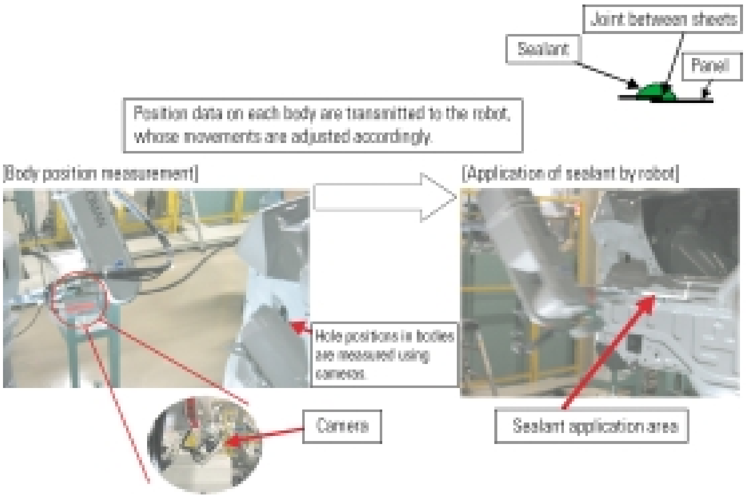


Fig. 6 Robot movement adjustment using camera measurement

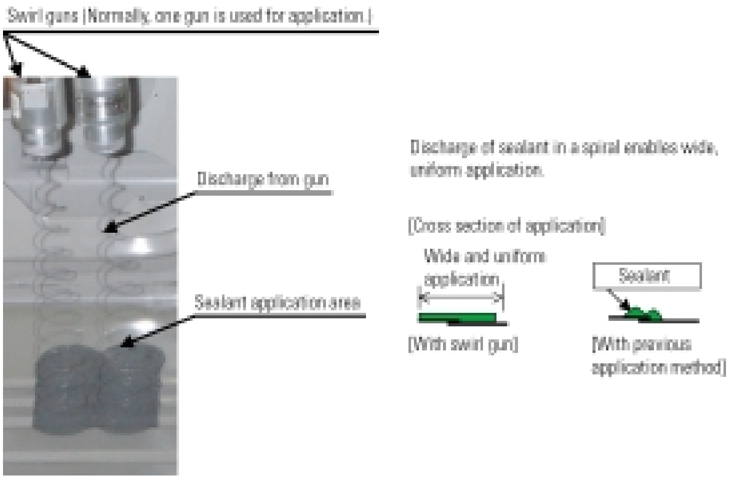


Fig. 7 Swirl-type sealing gun

4.3 Filler and top coat

For the filler and top coat, whose processes form the heart of the paint shop, technologies were introduced in three areas as follows:

(1) Minimization of VOC emissions

To minimize VOC emissions, waterborne paint was adopted for the filler and top coat and a high-solid clear (low-VOC type) coating was adopted.

(2) Minimization of employed paint volume

Technologies were adopted to minimize employed paint volume through increased paint transfer efficiency and through reduced losses during color changes.

Adoption of multiple-joint robots instead of the previously used straight-axis painting machines made it possible to spray paint on relevant parts of variously shaped bodies from optimal distances and angles, resulting in reduction of excessive spraying. Generally, the combination of the rotary-atomizer-type electrostatic paint guns, which give better paint transfer efficiency, and the air-atomizing electrostatic spray guns were adopted. (Rotary-atomizer-type electrostatic paint guns could not previously be used singly owing to difficulties with matching of the top-coat base color) But, together with paint improvement, rotary-atomizer-type electrostatic paint guns were improved to be able to match the top-coat base color without combination.

With regard to losses during color changes, the color-change valves were incorporated into the robot arms, thereby shortening the hose lengths from the guns to the cooler-change valves which need cleaning. And for the clear coating, the color-change valves were incorporated into the guns for significantly reduced paint loss during color changes.

(3) Improvement of paint appearance

Precise control of the spray guns by multiple-joint robots made it possible to dispense with touch-up spraying (touch-up spraying was impossible to avoid with the previously used straight-axis painting machines) and to minimize dripping and roughness (**Fig. 8**).

Fig. 8 Top coat application by robots

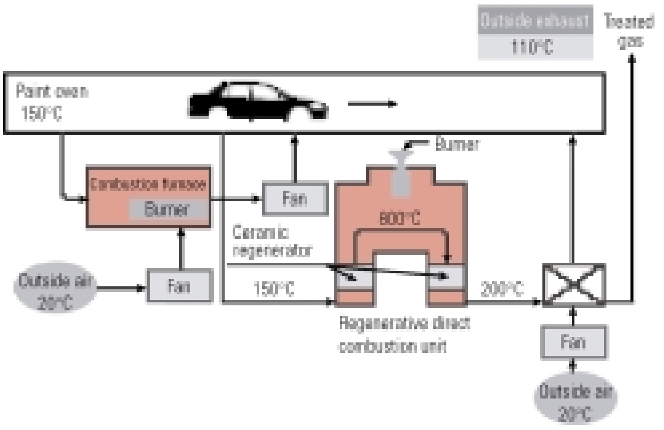


Fig. 9 Oven exhaust gas treatment system

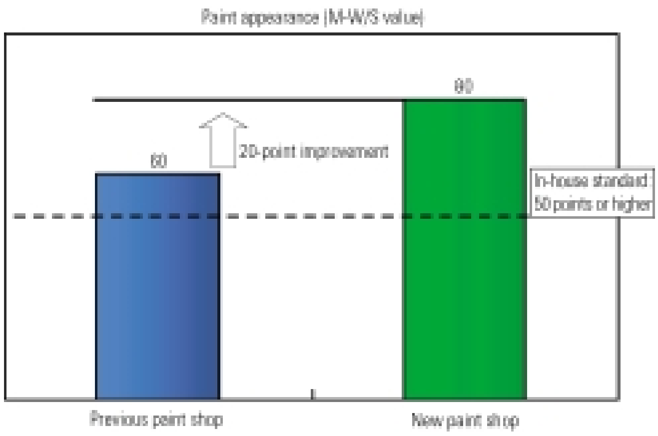


Fig. 11 Improved paint appearance

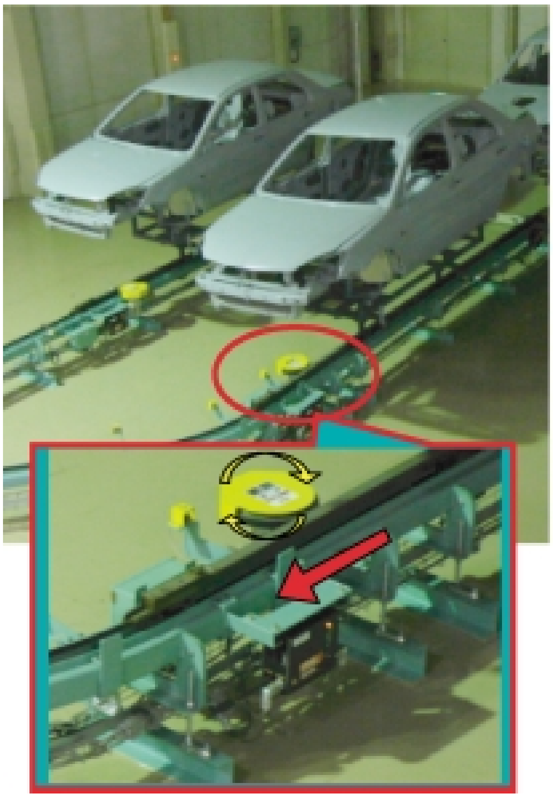


Fig. 10 Friction conveyor

4.4 Paint booths

Since water-borne paint is easily affected by the environment in the work area, the paint booths have control functions for temperature and humidity. And for improved management of the work area, the paint booths have glass walls that allow their interiors to be seen.

4.5 Ovens

All of the ovens are of the camel back and u-turn type, which has low heat losses. And as an environmental measure benefiting the area around the paint shop, a regenerative emission treatment system is used to prevent the release of harmful air pollutants (formaldehyde and acetoaldehyde) that are generated as paint hardens (**Fig. 9**).

4.6 Sanding area

The area where buffing is performed has a simple booth structure incorporating air-supply and -extraction functions and an underfloor water tank, so sanded-off paint fragments, which could cause paint defects if they escaped from the area, are not released.

4.7 Conveyor system

A friction conveyor, which propels body-transportation trolleys and hangers forward by means of pressed-on rollers and does not employ metal chains, was adopted to reduce plant noise (**Fig. 10**).

5. Measures for realizing high-quality paintwork at low cost

Adoption of waterborne paint resulted in higher painting costs since it necessitated investment in temperature and humidity control equipment and intermediate drying equipment and pushed up power costs. Nevertheless, an improved system including reduced labor costs and the aforementioned measures taken to minimize employed paint volume can be expected to keep painting costs approx. 20 % lower. Further, the introduction of waterborne paint, high-solid clear topcoat, and the latest painting equipment made possible paintwork with a smooth, glossy finish (**Fig. 11**).

6. Postscript

The service life of a paint shop is said to be 20 – 30 years, so the author of this paper, as a production engineer, feels privileged to have been involved with replacement of the paint shop at MMC's Mizushima plant (MMC's first such major project in 25 years). The author is grateful to have been able to engage in such worthwhile and satisfying work.

Yoichi KOYAMA

MITSUBISHI AUTO GALLERY

— Vehicles Which Mark An Era —

LANCER 1600GSR Rally (1973)

Overall length: 3,965 mm	Wheelbase : 2,340 mm
Overall width : 1,525 mm	Displacement: 1,597 cc
Overall height: 1,360 mm	Horsepower : 160 ps

Two time winner (1974 and 1976) of the world's most grueling rally – the SAFARI RALLY – and MITSUBISHI's most successful rally car. Based on the GALANT GTO and GALANT FTO, its demanding specifications are the reason this model is admired by many car lovers who take pride in their driving ability.

Introduction of MDC-Power

Fumitaka TOMONO*

1. Foreword

The plant that manufactures the new small-size aluminum engines (A9 engines) mounted in the European-produced COLT series was established as MDC-Power, a joint venture of Mitsubishi Motors Corporation (MMC) and DaimlerChrysler AG (DC) in Kölleda, Thüringen, Germany. **Fig. 1** shows the location of the plant.

State-of-the-art technologies were introduced in the production lines blending the production expertise of MMC and DC with the objective of ensuring high quality and high efficiency. This paper introduces the production line.

2. Outline of the plant

The plant has a site area of 400,000 m^2 and a building area of around 38,000 m^2, and manufactures 1.1-liter 3-cylinder and 1.3-liter/1.5-liter 4-cylinder gasoline engines. Three production lines, namely the cylinder block machining line, cylinder head machining line and assembly line, started operation on December 4, 2003. The production capacity is 250,000 units a year and the number of employees is 356 (as of October 1, 2004), and employment of around 70 % of the maximum production capability has been attained. Upon hiring the employees, 92 % were selected from among the local residents in Thüringen State as part of co-existence with the local community and contributing to the region.

Fig. 2 shows the site layout and the production line layout.

3. Characteristics of the production lines

3.1 Adoption of high-speed, high-precision machining centers

Linear motors are employed in the feeding mechanism of the machining units in the cylinder block and cylinder head machining lines to achieve high-speed and high-precision machining. These machining centers are laid out in parallel at each working process to achieve flexibility for production volume fluctuation and to improve the operation rate.

Shrink-fit tool holders replace the conventional collet chuck type in order to control the run-out of blade tips during high revolution of tools as the cutting speed is increased, for high-precision, high-speed machining. **Fig. 3** shows the layout of the cylinder block machining line.

3.2 Ensuring high quality and fulfillment of traceability

The machining lines ensure processing capability of Cpk = 1.33 and stabilize the quality at each process. Automatic inspection apparatus is adopted at the important quality processes to assure reliable quality. A tracking system was introduced in which data matrix

Fig. 1 Location of the plant

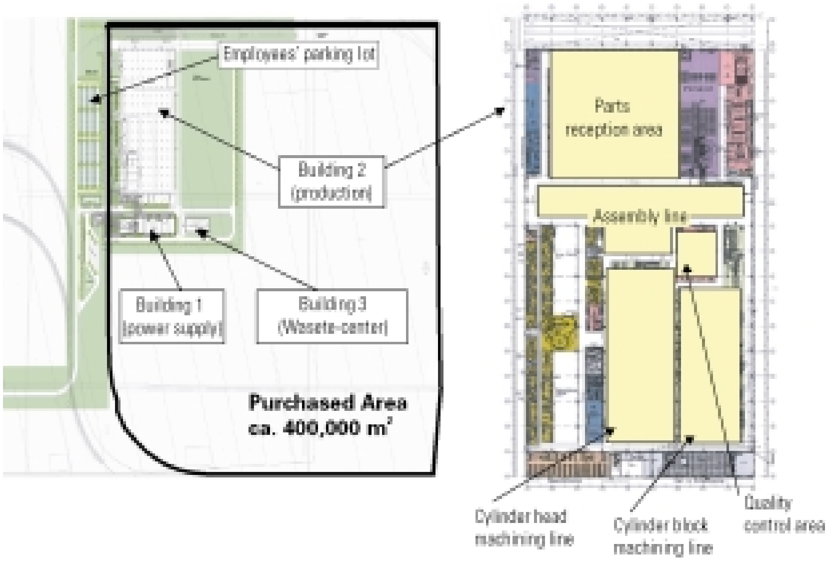


Fig. 2 Site layout and shop layout

* Production Engineering Powertrain Dept., Production & Logistics Office

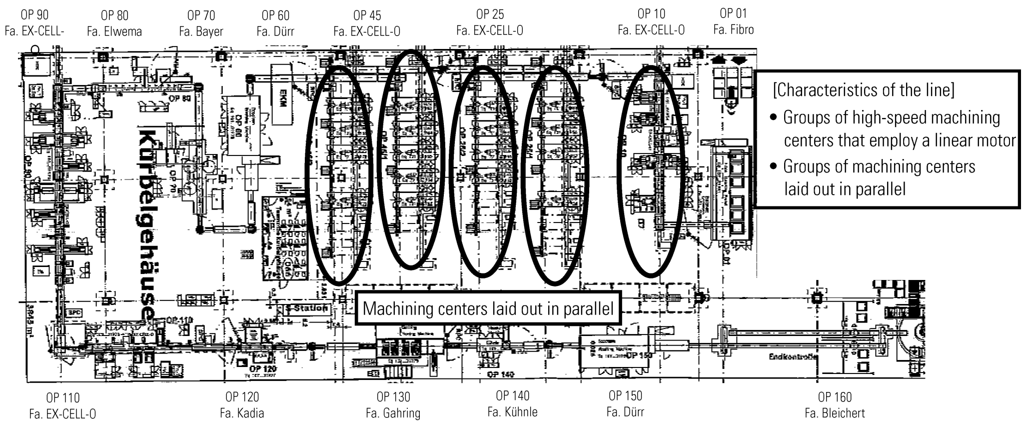


Fig. 3 Cylinder block line layout

Fig. 4 Data matrix code

Fig. 5 Writing data to the data matrix code

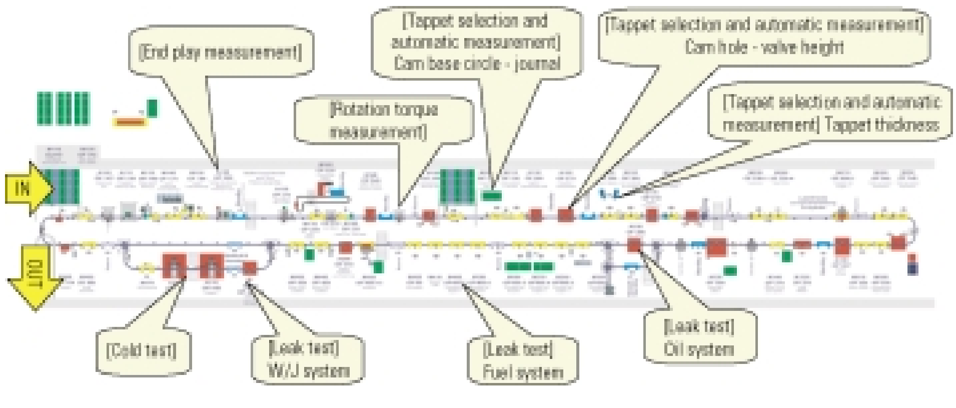


Fig. 6 Assembly line layout

codes are marked on the sides of parts. This system executes control by comparing the results of self-inspections and automatic inspections and measurements in order to facilitate tracking of defects in engines shipped to global markets. **Fig. 4** shows the data matrix code and **Fig. 5** shows the data recording process.

In the assembly line, an automatic full-inspection device is placed at important quality-related processes. All products undergo a monitoring test at the final process for guaranteeing the assembly quality and functions of supplied parts for all shipped products. Sample runs are conducted on 5 % of the products and dissembling inspection is conducted after sample runs on 0.5 % of the total products, to evaluate the quality of the engines under loaded conditions. **Fig. 6** shows the layout of the assembly line and the positions of the automatic full-inspection devices.

4 Efforts to reduce cost

At the planning stage of the facility for the A9 engines, both MMC and DC worked hard to reduce the

Table 1 Items employed to reduce A9 engine cost

Cylinder block machining line	• Single size for cylinder diameter • No machining on journal width • Adoption of roll taps
Cylinder head machining line	• Valve seat insertion at room temperature
Crank shaft machining line	• Simple oil hole machining form • No high-frequency quenching to shafts, taps or flange • Single tap diameter
Assembly line	• Adoption of shrink fit for crank shaft gears • Adoption of notchless metal for crank shafts and connecting rods • Adoption of engine No. dot stamp

facility investment and other costs by deploying the knowledge and experience of the engineers in both companies. Deep discussions were held with the development division, and ideas deemed difficult to achieve by either MMC or DC alone were proactively adopted in consideration of the past achievements of both companies. It was decided that part of the cost reduction items would be employed in the new direct 4-cylinder and V6 aluminum engines that MMC plans to manufacture in the future. **Table 1** shows examples of the cost reduction efforts.

5 Summary

The plant of MDC-Power is managed mostly with support from DC. MMC dispatched four production-technology related engineers to be resident in Germany, and one development engineer arrived at the site on January 1, 2003 for a long stay to support production startup.

The production volume will gradually increase and full-fledged operation as mass-production lines will start. When you visit Germany, please drop by at MDC-Power and observe the production lines that embody the best of MMC and DC technologies.

Finally, I would like to express my gratitude for those inside and outside MMC who have cooperated in the startup of the A9 engine production.

Fumitaka TOMONO

Technology Trends in the North American Market

Hideki HADA* Kenji TANABE**

1. Conditions in the NAFTA automobile market

The North American Free Trade Agreement (NAFTA) area is a huge and important market for automakers. By way of example, sales of new passenger cars and light-duty trucks in 2003 totaled about 16,680,000 units in the United States (US), 1,590,000 units in Canada, and 1,540,000 units in Mexico. Mitsubishi Motors Corporation (MMC) is among the automakers for which the NAFTA market is important; MMC sold 270,000 new vehicles in this market in 2003.

In the US, light-duty trucks, which include Sports Utility Vehicles (SUVs) and pickups, remain extremely popular; they accounted for 53.2 % of new-vehicle sales in 2003. If data on new-vehicle sales are analyzed, the preferences of US automobile users become apparent. Examination of data on numbers of cylinders and drivetrain configurations of new vehicles sold in the first six months of 2004 (**Fig. 1**) reveals that four- and six-cylinder engines and front-wheel drive (FWD) were predominant among passenger cars. Greater proportions of models with all-wheel drive (AWD) were sold among light-duty trucks. With large, six- and eight-cylinder models, however, the proportions of vehicles selected with FWD and rear-wheel drive (RWD) were significant. Notably, AWD models accounted for 43.5 % (under half) of six-cylinder light-duty trucks. The importance of offering two-wheel-drive (2WD) models, even among SUVs and pickups, which are traditionally associated with AWD, can be clearly seen.

With Mitsubishi GALANT-class midsize passenger cars, engine configurations selected by customers differ according to the market positioning of individual models (**Fig. 2**). Strong-selling sedans such as the Honda ACCORD and Toyota CAMRY are marketed with an emphasis on V6 engine performance, but it can be seen from **Fig. 2** that most of such sedans are actually sold with less expensive inline four-cylinder engines. In the market for midsize sedans, therefore, automakers are sensible to maximize profitability with models that have inline four-cylinder engines even though they highlight the high performance of V6 models in their promotional activities.

With Mitsubishi ENDEAVOR-class midsize SUVs, nearly half of customers select 2WD models despite the widely perceived association of SUVs with AWD (**Fig. 3**). With the Mitsubishi ENDEAVOR, 45.2 % of sales in the first six months of 2004 were made in four relatively warm states: Florida, California, Texas, and Illinois. AWD is not absolutely necessary in winter in these

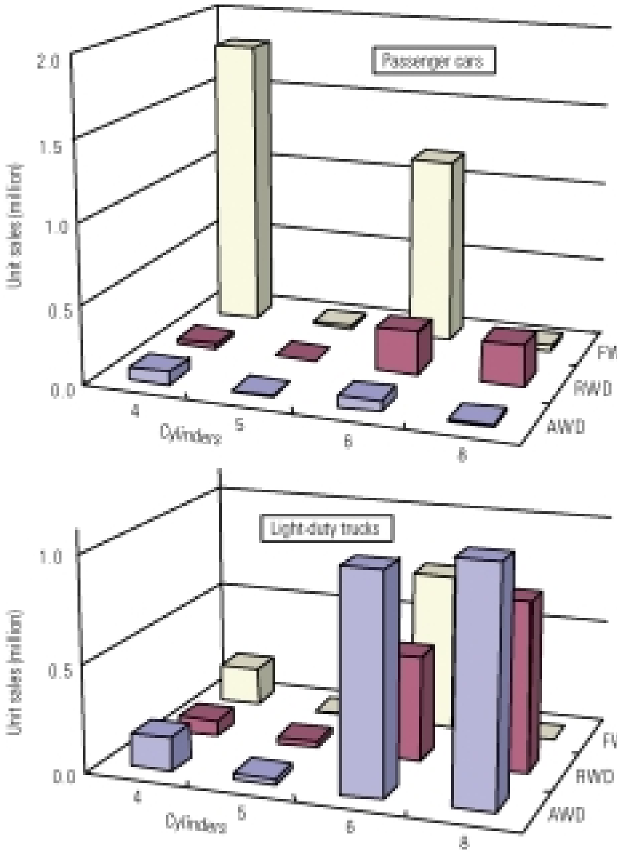


Fig. 1 US new-vehicle unit sales in first half of 2004 by number of cylinders and drivetrain configuration

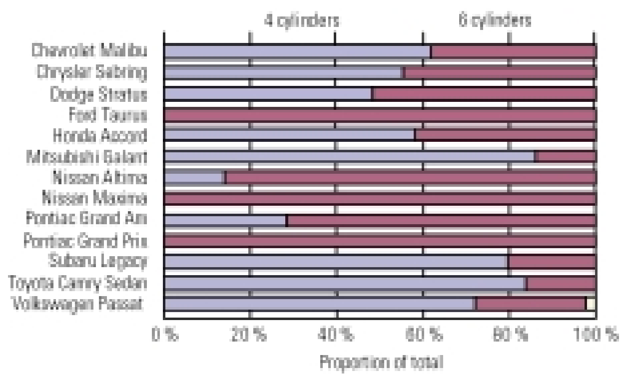


Fig. 2 US unit sales of new midsize passenger cars in first half of 2004 by number of cylinders

* Technical Information Group, Technical Management Dept., Mitsubishi Motors R&D of America (MRDA)
** Regulatory & Certification Affairs Group, Quality Affairs Dept., Mitsubishi Motors R&D of America (MRDA)

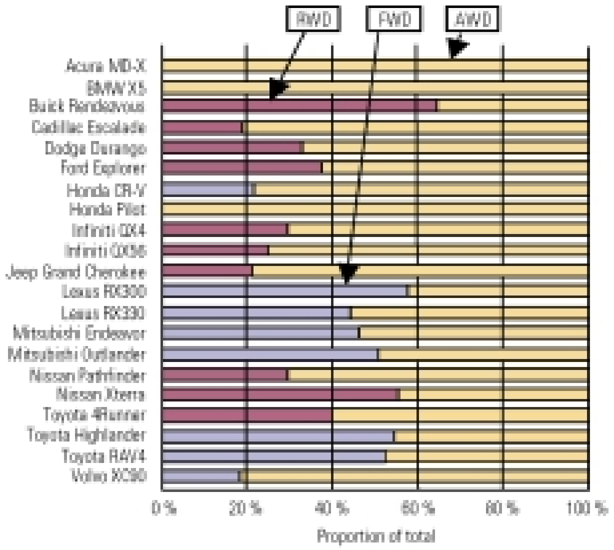


Fig. 3 US unit sales of new midsize SUVs in first half of 2004 by drivetrain configuration

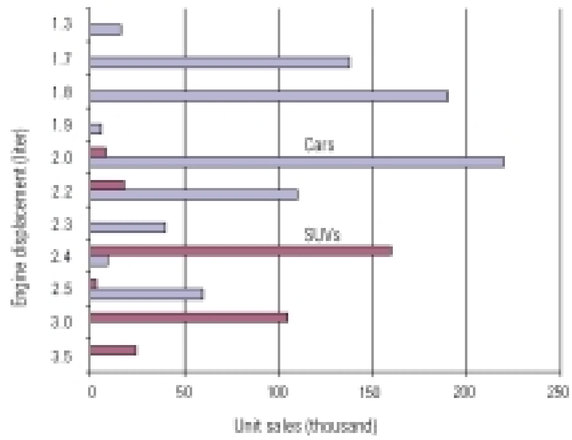


Fig. 4 US unit sales of new compact vehicles in first half of 2004 by engine displacement

states, so the importance of offering 2WD models is particularly great there.

With Mitsubishi LANCER-class compact passenger cars, the most popular engine displacements are 1.8-liter and 2.0-liter (**Fig. 4**). With compact SUVs, the most popular engine displacement is 2.4-liter. However, models with engine displacements of 3.0-liter and larger are also sold in large numbers.

In the US, the traditional perception that bigger is better remains predominant. However, there are signs of growing awareness of the attraction of vehicles that are small and smart. Following the success of Toyota's Scion brand, other B-segment models such as the Honda Fit, Suzuki IGNIS, Nissan Cube, and BMW 2-Series have been introduced. Although these models are small, they have high levels of equipment (DVD navigation systems and so on) and are thus helping to destroy the traditional perception that small equals cheap.

With passenger cars, a return to a focus on high performance can be expected; customers are likely to be strongly attracted to RWD and AWD. The catalyst is the adoption of RWD in the Chrysler 300 and Dodge Magnum, which are large sedans. General Motors will join this movement by launching, from the 2006 model year, RWD sports cars based on its newly developed Kappa architecture. A likely result is that customers will come to perceive an association between high performance and RWD. Japanese and European automakers will, at the same time, introduce AWD in their high-performance models to achieve differentiation.

2. Relationships between state statute, regulations, and standards

Each of the 50 states that constitute the US has its own constitution and laws. The federal government's role is limited to affairs that extend beyond any individual state's jurisdiction, so it is necessary for automakers to simultaneously satisfy the road-transportation laws and other regulations of each individual state. In addition, the auto industry has many self-imposed regulations and standards. When developing vehicles, therefore, automakers have to take into account huge amounts of regulatory information.

The challenges facing automakers are clearly exemplified by issues related to driver distraction. Driver distraction results from a driver's use of a cellphone or navigation system while driving, and it causes the driver to pay insufficient attention to the task of driving the vehicle. Unfortunately, state laws, guidelines, and standards are inter-related in complex ways.

At the federal level, there is no legislation prohibiting the use of cellphones at the wheel. However, certain states (for example, New York State and Washington, DC), certain counties (for example, Miami Dade County, Florida), and certain cities (for example, Brooklyn, Ohio) have their own laws prohibiting this activity. In other words, different segments along the same highway may be subject to different regulations; the situation is extremely difficult for drivers to grasp.

Federal Motor Vehicle Safety Standards and other federal regulations take precedence over state laws, so the federal government could, in theory, resolve the confusion resulting from regional legal differences by issuing regulations. However, the federal government has not been able to do so in practice because of the problem of needing to clearly delineate actions that are permissible for drivers. The auto industry has responded by creating its own guidelines and by making an effort to take harmonized measures. At the same time, experts in ergonomics work on the creation of International Organization for Standardization (ISO) and Society of Automotive Engineers (SAE) standards. Guidelines and standards of the kind mentioned here are not directly enforceable, but automakers accept them as expertly prepared reflections of their overall position and are, in practice, obligated to comply with them. The consequence is that, although there is much

Table 1 Alliance of Automobile Manufacturers distraction guidelines

Version	Issue Date	Completed Sections
1.0	2000/12	Principles only
2.0	2002/4	1.1, 1.2, 1.3, 2.2, 2.4, 3.1, 3.2, 3.5, 4.1, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6
2.1	2003/11	Version 2.0 + 1.5, 2.3, 3.6, 4.2, 4.3
3.0	2004/12	Version 2.1 + 1.4, 2.1, 3.3, 3.4

Table 2 EDR-related documents issued by SAE VEDI Committee

Number	Content
J1698	EDR Concept
J1698-1 Dec 2003	EDR Output Data Format for Frontal Impact Event
J1698-1 Version 2	EDR Output Data Format for Impact and Rotational Events
J1698-2 May 2004	Identification Method for EDR Data Extraction Protocol

information for automakers' reference, the industry has no single, consistent, absolutely accepted set of rules.

Guidelines and standards of the kind mentioned above are in some cases not issued until they have been studied and discussed by working groups over a period of years. Often, not even an overview of proposed guidelines and standards is available while deliberations are in progress. MRDA's Technical Information Group and Regulatory & Certification Affairs Group participate in many working groups. Up-to-date information on these activities can be seen on the NAFTA Technical Report page on the MRDA intranet (http://10.79.3.7).

3. Overview of guidelines on driver distraction

The Alliance of Automobile Manufacturers (AAM) has been compiling voluntary industry guidelines related to driver distraction since 2000, and it has already issued a number of sections (**Table 1**). Version 1.0, which the AAM issued in December 2000, consists of principles only, but version 2.0 and subsequent versions include evaluation criteria and evaluation methods. By way of example, section 3.5 of version 2.0 specifies that the system reaction time shall be a maximum of 250 ms and that if more than two seconds are taken the system shall indicate that it is responding. And section 3.6 of version 2.1 requires that, while a vehicle is being driven, any dynamically indicated data that do not contribute to safety shall be indicated dimly or have their monitor turned off or be switched to some other window. Version 3, which was completed at the end of 2004, includes requirements related to the basics of the interface. For example, it requires that the display be located within a downward viewing angle of 30° and states that a permitted operation is one for which a single visual recognition period is no longer than two seconds and for which the overall recognition time through completion of the operation is no longer than 20 seconds.

Defining operations that may be performed at the wheel is extremely difficult because it requires not only quantification of increases in the driver's operating burden caused by the operations but also establishment of clear numerical standards. SAE standard J2364 states that an operation that may be performed at the wheel is one for which the total task time is no longer than 15 seconds or one that, when performed by a person wearing special goggles with a liquid-crystal shutter, can be completed with a total shutter-open time no longer than 20 seconds. The test technique with which special goggles are used is called occlusion. In the ISO/TC22/SC13/WG8 committee, a related, proposed standard (ISO16673) is under consideration. Another approach is based on the view that an operating task for a telematics device should be permitted at the wheel provided the distraction it causes is no worse than that caused by normal operation of the radio. The aforementioned WG8 committee is also considering a method for deciding whether operations at the wheel are permissible or not by employing the results of simulated lane-change tasks. There is no single tool that can be applied to all cases, so it is necessary to effectively combine existing tools to establish evaluation techniques.

4. Overview of standardization for data recorders

Onboard electronic data recorders (EDRs), which record operating data including data on accident impacts, can be used to clarify the causes of accidents, so they have the potential to enhance safety in transportation.

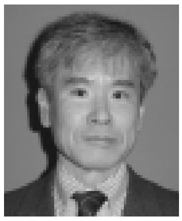
The US Department of Transportation (DOT) issued in June 2004 a Notice for Proposed Rulemaking in connection with EDRs. The DOT's proposals included a harmonized output format for data stored in EDRs. By a deadline in mid-August 2004, the DOT had received more than 100 comments on its proposals. The large number of comments reflected the fact that many people are concerned about this issue.

At about the same time, the SAE was working on creation of standards for a harmonized output format for EDR data. The SAE's Vehicle Event Data Interface (VEDI) Committee has issued four standards (**Table 2**). The J1698 standard issued by the VEDI Committee is based on the concept that an EDR is a function, not a box, and it defines the items to be standardized as only EDR data that are, by some means, downloaded outside of the vehicle; it leaves the method for obtaining the data via the vehicle bus, the method for storing the data, and the method for downloading the data for individual automakers to choose. This standard defines the data name, sampling frequency, data resolution, hexadecimal structure, and other attributes of 65 data elements; the data definitions can be applied with nearly all EDR applications.

5. Summary

With regard to the NAFTA market, the MRDA Technical Information Group conducts wide-ranging research into market trends, technology trends, trends in equipment adoption, and trends among MMC's competitors, and it participates widely in the creation of guidelines and standards by industry bodies. It makes the resulting information available via the MRDA intranet, and keeps the information up-to-date. The MRDA Technical Information Group will continue to work in diverse, flexible ways to support MMC's activities in North America. We look forward to hearing from anyone who requires information.


Hideki HADA


Kenji TANABE

MITSUBISHI AUTO GALLERY

— Vehicles Which Mark An Era —

COLT 1500 Super Sports (1968)

Overall length: 3,910 mm	Wheelbase : 2,285 mm
Overall width : 1,490 mm	Displacement: 1,498 cc
Overall height: 1,395 mm	Horsepower : 170 ps

MITSUBISHI's first high-performance sport sedan. Superior performance achieved through the use of features including a 1,500 cc engine, front disk brakes, bucket seats, floor-type stick shift and tachometer in a COLT 1100 body.

LANCER EVOLUTION VIII for EU

Hideyuki IWATA*

LANCER EVOLUTION VIII won the 2004 Motor Sport Car of the Year award (Sportive de l'année 2004) by the major French motor sport magazine "Echappement".

"Echappement" (exhaust pipe) is a monthly magazine with 250,000 readers and a history of 37 years. Selection of the Motor Sport Car of the Year began in 1982 and this year marked its 23rd anniversary. The subjects for Car of the Year are sporty models sold in France in 2004, including Porsche 911, Benz SLK, Audi A3, Renault Megane RS and other revered models.

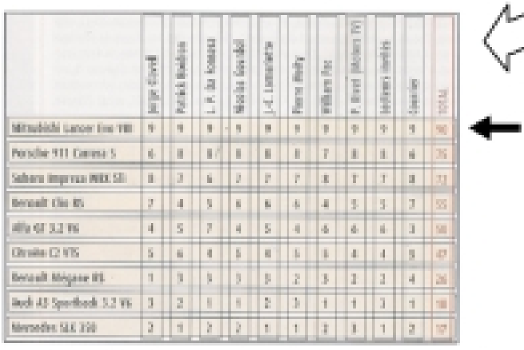
Evaluation is conducted on public roads and circuits, but the price is also a factor. Six journalists, three readers and one rally driver vote for the winner through allocation of points.

Nineteen models were nominated this year, and nine cars were selected for a test drive. LANCER EVOLUTION VIII received a perfect review, where all judges awarded the top score for the first time in the award's history (full marks: 90 points).

Development of the 2006 model has already started, and LANCER EVOLUTION IX, with a more advanced engine, transmission and undercarriage will be launched into the market in autumn 2005.

Winning the Car of the Year in Europe, where evaluation of cars is strict, signifies that the technology, concept, performance and quality of LANCER EVOLUTION

Article on LANCER EVOLUTION VIII winning the 1st prize



	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL
Mitsubishi Lancer Evo VIII	9	9	9	9	9	9	9	9	9	9	90
Porsche 911 Carrera S	6	8	8	8	8	8	7	8	8	6	75
Subaru Impreza WRX STi	8	7	6	7	7	7	8	7	7	8	[illegible]
Renault Clio RS	7	4	5	6	6	6	4	5	5	7	55
Alfa GT 3.2 V6	4	5	7	4	5	6	6	6	6	3	[illegible]
Citroën C2 VTS	5	6	4	5	6	5	5	4	4	5	47
Renault Mégane RS	1	3	3	3	3	2	3	2	2	4	26
Audi A3 Sportback 3.2 V6	3	2	1	1	2	3	1	1	3	1	18
Mercedes SLK 350	2	1	2	2	1	1	2	1	1	2	17

LANCER EVOLUTION VIII winning outstanding evaluation results

have caught up with and overtaken European cars. It is a proud step forward for us as development engineers that LANCER not only performs superbly in rallies with the World Rally Championship (WRC) at the summit, but has also truly advanced into the world of high-performance cars.

<Postscript>

After this article was contributed, news was received about winning a prize in the United States as well:

Magazine: SPORT COMPACT CAR
Award: Sport Compact Car of the Year 2005

Trophy

* FF Product Development Project C-seg, Product Development Office

New Mitsubishi COLT for Europe

In 2004, the new COLT won the Golden Steering Wheel Award in the Small Car category.

The Golden Steering Wheel, which was first presented in 1976 and is seen as the equivalent of a German Car of the Year award, is given each year by the German Sunday newspaper ‘Bild am Sonntag’, which has the largest readership (10.7 million people) of any Sunday newspaper in Europe. The selection process for the award begins with a reader survey and ends with evaluation by a jury consisting of media personalities, racing drivers, and others.

Other final-selection candidates were the Renault Modus, the Peugeot 1007, and the smart forfour (another joint development). (The smart forfour took second place in the category.) The new COLT was the only car in the category to earn a top-three ranking for all evaluation criteria. Key factors in the new COLT’s selection for the award included its versatility, seating comfort, spaciousness, usability, and build quality.

The following describes the outline of this prize-winner COLT.

NEW PRODUCTS

New Mitsubishi COLT for Europe

The new Mitsubishi COLT for Europe went into production, initially in five-door, gasoline-engine form, in April 2004 in Born, a city in a southern part of the Netherlands that is sandwiched between Belgium and Germany. It went on sale throughout Europe in June 2004. A three-door version went into production in December 2004 and went on sale in February 2005.

1. Targets

In terms of platform concept and external appearance, the new COLT for Europe is essentially the same as the new COLT for Japan. However, its interior styling and technologies are tuned to make it competitive with European B-segment cars in the European market. Specific development targets were

- fashionable styling;
- low fuel consumption and high performance (to be achieved by means of new engines);
- high safety (with a 4☆ Euro NCAP rating);
- high practicality and space utility; and
- handling stability and ride comfort suiting European preferences.

2. Features

(1) Europe-oriented powertrain

The engine lineup includes newly developed gasoline engines in 1.1-liter, 1.3-liter, and 1.5-liter displacements. (There is strong demand for the 1.1-liter displacement in southern Europe.) The gasoline engines are made by MDC-Power, a company that is jointly owned by MMC and DaimlerChrysler. Reflecting extremely strong recent demand for diesel engines in Europe, the engine lineup also includes a three-cylinder version of a 1.5-liter diesel engine that was developed for new Mercedes A-Class. The diesel engine is procured from DaimlerChrysler. The engine lineup also includes a turbocharged 1.5-liter gasoline engine, which

External view of COLT 5-door

is used in the three-door version of the car. Transmissions are manual and AllShift types made by GETRAG of Germany.

(2) User-friendly cabin

A roomy cabin and a front-seat slide range of 260 mm provide comfort for people ranging from a DM95 to AF5 (95th-percentile Dutch male to a 5th-percentile American female), enabling the car to accommodate users in racially diverse Europe. And the cabin meets diverse storage needs; the floor console contains three cupholders that can also be used as cellphone holders; front-seat occupants are provided with door pockets and seat-side boxes; and the glove box not only provides space for pens, coins, and other small items but can also hold a cool-box to which chilled air is fed. In the five-door version, further versatility is provided by a 60:40-split rear seat that has slide and tumble functions and can be removed from the car.

(3) Europe-oriented high handling stability and dynamic performance

Owing partly to the benefits of driving trials held on public roads in Europe, handling stability is comparable with that of competing European cars even during high-speed cruising on autobahns and during high-speed driving in mountainous regions. Further, the version with the turbocharged gasoline engine has dynamic performance that enables a maximum speed of 210 km/h.

(4) High safety

Fitted front airbags for the driver and front passenger as the standard, the new COLT for Europe has a level of collision safety (verified through in-house tests) corresponding to a 4☆ Euro NCAP rating. Side airbags and curtain airbags are optionally available for even greater occupant protection. Active safety is promoted by the Mitsubishi Active Stability Control System.

External view of COLT CZT turbo 3-door

3. Major specifications

Major specifications of the new COLT for Europe are shown in the following table.

Specifications		Model	COLT 5-door				COLT CZ3 3-door					COLT CZT turbo 3-door
Dimensions	Overall length	(mm)	3,870				3,810					3,820
	Overall width	(mm)	1,695									
	Overall height	(mm)	1,550				1,520					
	Wheelbase	(mm)	2,500									
	Treads	Front (mm)	1,460									
		Rear (mm)	1,445									
	Min. ground clearance	(mm)	154									
Engines	Model		3A91	4A90	4A91	OM639	3A91	4A90	4A91	OM639		4G15
	Displacement	(cc)	1,124	1,332	1,499	1,493	1,124	1,332	1,499	1,493		1,468
	Max. output	(kW/rpm)	55/6,000	70/6,000	80/6,000	70/4,000	55/6,000	70/6,000	80/6,000	50/4,000	70/4,000	110/6,000
	Max. torque	(Nm/rpm)	100/3,500	125/4,000	145/4,000	210/1,800	100/3,500	125/4,000	145/4,000	160/1,600	210/1,800	210/3,500
Transmissions	5 M/T		○	○	○	○	○	○	○	○	○	○
	6-speed AllShift			○	○	○		○				
Chassis	Steering		Rack and pinion (with electric power assistance)									
	Suspension	Front	MacPherson struts									
		Rear	Torsion beam									
	Brakes	Front	14-inch ventilated discs									15-inch ventilated discs
		Rear	8-inch drums		14-inch discs	8-inch drums		14-inch discs		8-inch drums	14-inch discs	
	Tires	Front	175/65R14		195/50R15	175/65R14		195/50R15		175/65R14	195/50R15	205/45R16
		Rear	175/65R14		195/50R15	175/65R14		195/50R15		175/65R14	195/50R15	205/45R16

(FF Product Development Project B-seg, Product Development Office: Nagasawa, Kawanami, Hatashita, Sonobe)

COLT PLUS

The COLT PLUS is a compact car of new genre, which was introduced as the COLT series in line with the 2005 minor change in the timing of the COLT launched in November 2002. Retaining the classy feel and ease of use of the COLT, the new COLT PLUS with an extra spacious luggage compartment and greater ease of use was launched on October 25, 2004. This compact car makes leisure time and hobbies more fun.

1. Objective

Targeted at males and females in their twenties and thirties, young families and males and females in their fifties or older who often carry leisure and hobby gear as well as children's goods, the COLT PLUS is designed to make people and goods easier to carry in a more comfortable manner in spite of its compact size, by adding snappy driving and easy-to-use utilities to the existing features of the COLT.

This time the RALLIART, a sporty model powered by a turbocharger engine, has been added including the COLT to expand the range of potential customers of the entire COLT series.

2. Product features

2.1 Exterior design

Based on the chic and sporty world which is distinctive characteristics of the COLT, the COLT PLUS brings elegance with its smooth wrap-around rear curves, offering a sleek, elegant and sporty image not expected of a conventional compact wagon.

With the COLT image captured in the flowing one-motion silhouette, the COLT PLUS is clearly identified by the rear overhang that has been stretched by approximately 300 mm. The soft round form that flows smoothly from nose to sloping tail projects a sense of speed and graceful elegance. The grille enhances the classy look of the front design, and bumpers have been redesigned with a more sporty character.

Eight body colors including three new colors based on a sophisticated adult sense are available.

2.2 Interior design

Based on the COLT world that creates richness by eliminating unnecessary elements, the COLT PLUS has a high-quality, mature feel with newly designed meters and coordination between color and material, creating a more special feeling, greater functionality and more room.

Three interior schemes are available: the dark blue/black two-tone Sporty interior, the dark brown/beige two-tone Warm interior, and an interior exclusive to the RALLIART with accentuated sports sense conveyed by the accent panel and seat fabric.

2.3 Packaging

Accessibility to multistory car parks and maneuverability in traffic, which are essential for any compact car, have been achieved by making the wheelbase, overall width and overall height of the vehicle the same as those of the COLT thanks to the shared common platform. At the same time, the rear overhang has been stretched by approximately 300 mm to give a more roomy cabin with spacious luggage compartment.

The rear seats have been changed to fixed-type folding seats with sufficient height for the seat back. The hip point has been lowered at the position where ample leg room is secured for more head room and to facilitate getting in and out of the vehicle. Meanwhile, the 6:4 split seat back with 8-step reclining mechanism and an arm rest with cup holders are provided for the comfort of rear passengers.

Future regulations concerning the required strength of the luggage compartment of the rear seat and height of front and rear headrests have been met in advance.

2.4 Driving

(1) Powertrain

The standard model is powered by a new four-cylinder in-line aluminum block engine (type 4A91), which is compact, lightweight and among the top in class in every performance aspect and is installed on the COLT manufactured in Europe, and is combined with CVT*1. In addition to delivering the best-in-class driving performance thanks to improved engine performance in the mid-to-high speed range and better acceleration feeling by improving the torque converter characteristics and CVT shifting control, fuel economy in actual traffic has been improved by adopting the ATF*2 Warmer.

For a shifter of CVT, a floor shift lever with Sport Mode is now available in addition to the column shift lever, and is adopted for 2WD vehicles and the RALLIART. With this specification, the driver can now change the gear ratio at will as if shifting a manual transmission, and thus there is no compromise of driving pleasure.

*1: continuously variable transmission

*2: Automatic Transmission Fluid (oil exclusive to automatic transmission)

(2) Driving stability and ride comfort

The COLT PLUS has been given high body rigidity by reviewing the body joint structure, placing reinforcing members effectively and examining the plate thickness of materials while limiting the increase in body weight to less than 10 %. In addition, by tuning the damping force of shock absorbers and characteristics of the springs, a fine balance of outstanding handling, stability, and ride comfort has been achieved.

In 4WD vehicles, ride comfort has been improved by using urethane bump stoppers for the rear.

Furthermore, the steering feel of electric power steering has been improved by upgrading the assist control logic and further tuning.

(3) Quietness

Sound insulation performance and quietness have been improved by increasing the vibration absorption of the exhaust system with spherical joints (standard model) and adopting interior materials of sound-absorption construction in addition to reducing vehicle body vibration with the highly rigid floor inherited from the COLT.

(4) Environmental performance and safety

The 2WD standard model has achieved emission levels that are 75 % lower than Japan's 2005 standards (4☆ rating) while the 4WD model has achieved levels that are 50 % lower than the 2005 standards (3☆ rating). At the same time, both the 2WD and 4WD models meet the 2010 fuel consumption standards +5 % in the 10·15 mode driving cycle, and all models qualify for 'Green Tax' exemptions.

Inheriting the straight frame platform and highly rigid press doors from the COLT, the COLT PLUS offers even greater collision safety equivalent to JNCAP*3 5☆ level by reviewing materials for the front side members and reinforcing major areas. Consideration has also been given to collision safety for infants by allowing the rear seat to be equipped with an ISO-FIX compliant child seat of the tether anchor type.

*3: New Car Assessment Program

(5) Sporty model RALLIART

The turbocharger engine (type 4G15) is installed on the RALLIART, a sporty model focusing on driving performance and positive driving pleasure, in combination with CVT as in the standard model. To maximize that sporty driving feel, the gear ratios have been optimized in the Ds range and Sport Mode.

In terms of steering stability and ride comfort, the damping force of shock absorbers and spring constant of springs have been increased based on the standard model in addition to an increase in the front stabilizer diameter to achieve higher roll stiffness. Besides, the bushings of the lower arm have been turned to provide transverse stiffness.

The electric power steering has been given a sporty character by shortening the gear ratios and doing model-specific tuning of the assist control characteristics.

And even though the RALLIART, thanks to various model-specific tuning, boasts driving and handling performance surpassing those of competitive compact cars installed with a supercharged engine and manual transmission, it meets emission levels (3☆ rating) that are 50 % lower than the 2005 standards, thus delivering both excellent driving performance and low emission levels.

Electric Tailgate

One-Touch Folding Seat

2.5 Easy-to-use utility

Special attention has been paid to ease of use of the luggage compartment, both in terms of space and ease of use for daily life.

The Electric Tailgate, which is opened and closed with a switch built into the key to facilitate access to the luggage compartment, is adopted for the first time in this class. This mechanism enables the tailgate to be easily opened and closed without touching it when there is a lot of luggage or in a rainy day. Reversal during opening/closing operation is enabled by the switch built into the key, the closing switch provided on the bottom of the tailgate, and tailgate outer handle switch. Furthermore, in case of emergency, a mechanism which automatically reverses the tailgate movement when it detects an obstacle is provided for safety.

The One-Touch Folding Seat, which folds down the seat back at the pull of a lever located inside the luggage compartment eliminating the need to go to the rear door for loading large luggage, are adopted to make it easier to load large luggage from the tailgate.

In addition, for 2WD vehicles, a Flexible Cargo Floor is adopted, which has a two-stage height-adjust feature, enabling the luggage compartment to be tailored to meet carrying requirements of luggage of varying shapes and sizes. The luggage compartment volume of 280 liters (VDA method[*4]) with the flexible cargo floor at the upper position can be expanded to 364 liters (VDA method) by moving the floorboard to the lower position. With this lower position, an underbox (specification without spare tire) of 25 liters (VDA method) is provided beneath the cargo board. The underbox, which is made of resin and is detachable, is ideal for storing car-washing materials and wet objects. The cargo board is split into two parts in the longitudinal direction. Since each part moves up and down independently, and the rear of the board can be opened and closed either at the upper or lower position, the cargo board can meet the various usage requirements of customers.

*4: Measuring method of luggage compartment volume specified by the German Association of the Automotive Industry

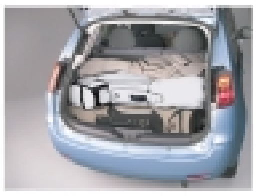
A board at upper position

A board at lower position

<Storage of cooler boxes (possible to close the board)>
(No spare tire type)

<Foliage plant (height of 1 m)>
(No spare tire type)

<Four suit cases>



<Four golf bags>

Flexible Cargo Floor

3. Main specifications

Main specifications are shown in the table below.

Specifications		Motor vehicle type	COLT PLUS		
			Mitsubishi DBA-Z23W	Mitsubishi CBA-Z27W	Mitsubishi CBA-Z24W
			2WD		4WD
			CVT		
Dimensions	Overall length (mm)		4,185	4,170	4,185
	Overall width (mm)		1,680		
	Overall height (mm)		1,550		
	Wheelbase (mm)		2,500		
	Tread	Front (mm)	1,460		
		Rear (mm)	1,445	1,450	1,430
	Interior length (mm)		1,820		
	Interior width (mm)		1,400		
	Interior height (mm)		1,240 (1,170: With sunroof)		
	Vehicle weight (kg)		1,070	1,150	1,140
	Minimum turning radius (m)		4.7 (4.9: When 15-inch tires are fitted)		
Engine	Engine type		4A91	4G15 Turbo	4A91
	Displacement (cc)		1,499	1,468	1,499
	Valvetrain and number of cylinders		DOHC 16 valves, 4 cylinders		
	Max. horsepower {kW (PS)/min^{-1} Net}		77 (105)/6,000	108 (147)/6,000	75 (102)/6,000
	Max. torque {Nm (kgf·m)/min^{-1} Net}		141 (14.4)/4,000	180 (18.3)/2,500	138 (14.1)/4,000
	Fuel supply system		ECI-MULTI (Electronically controlled fuel injection)		
Running gear	Steering		Rack & pinion (with power steering)		
	Suspension	Front	MacPherson strut type		
		Rear	Torsion beam type		Trailing axle type
	Brake	Front	Ventilated disc (14-inch)	Ventilated disc (15-inch)	Ventilated disc (14-inch)
		Rear	Leading trailing (8-inch)	Disc (14-inch)	Leading trailing (8-inch)
	Tire		175/65R14	185/55R15	175/65R14

(FF Product Development Project B-seg, Product Development Office: Yoshimatsu, Amano, Katagiri, Furukawa)

NEW PRODUCTS

Newly Developed Compact, Aluminum Gasoline Engine

A compact, aluminum gasoline engine was developed by Mitsubishi Motors Corporation (MMC) for use in the Mitsubishi COLT and smart FORFOUR that went on sale in Europe in the spring of 2004, in the Mitsubishi COLT PLUS that went on sale in Japan in October 2004, and in the 2005 Mitsubishi COLT.

1. Targets

The basic concept was to develop an engine optimally suited to new-concept cars. The models in which the engine was intended to be used reflect the pursuit of innovative styling, interior spaciousness, sporty performance, and environmental compatibility. The engine attributes necessary for these goals to be achievable were identified as lightness, compactness, high output, low fuel consumption, and low exhaust emissions.

The engine project was begun as a joint effort by MMC and DaimlerChrysler (DC), with MMC handling the development mainly and MDC-Power GmbH, a company jointly established by MMC and DC, handling production. In this regard, the project was deemed important not only as a means of creating a superior engine but also as a means of deepening and advancing the collaborative relationship between MMC and DC.

2. Features

To meet the respective vehicles' performance requirements, there are three engine displacements: 1.1-liter (with three cylinders); 1.3-liter (with four cylinders); and 1.5-liter (with four cylinders).

All three engine displacements are used in the Europe-specification Mitsubishi COLT and smart FORFOUR. The Europe-specification Mitsubishi COLT and smart FORFOUR are each available with a choice of manual transmission or automated manual transmission. For a given engine displacement, nevertheless, the engine specifications are uniform regardless of individual combinations of vehicle model and transmission type.

The 1.3-liter and 1.5-liter engine displacements are used in Japan. The engine structure for Japan differs from the engine structure for Europe in several respects: Major components were altered to ensure optimal fuel economy in the operating conditions that prevail in Japan; exhaust gas recirculation (EGR) was adopted; and certain components are differently positioned to accommodate a continuously variable transmission (CVT).

Technologies employed to realize the required engine attributes in compliance with the development concept are described below. Most technologies and components actually contribute to multiple desired engine attributes. The correlation between items and the benefits they yield is shown in **Table 1**.

2.1 Lightness and compactness

Design optimization, material optimization, and component integration were identified as effective

Table 1 Technologies and purposes thereof

Item \ Purpose	Lightness and compactness	High output; low fuel consumption	Low exhaust emissions	Low vibration; low noise	High reliability
Die-cast aluminum cylinder block	×				
Knock-suppressing cylinder head	×	×	×		
Ultra-thin, one-layer metal cylinder-head gasket			×		
Plastic cylinder-head cover	×			×	
Dual overhead camshafts with valves directly actuated by cams	×	×	×		×
Continuously variable intake-valve timing (MIVEC system)		×	×		
Hollow camshafts	×				
Lightweight, low-friction main moving parts	×	×			
Torsional damper on crankshaft pulley (1.5-liter variant only)				×	×
Primary balancer shaft (1.1-liter variant only)				×	
Cam actuation by means of timing chain	×	×			×
Chain case integrated into engine-mounted oil pump	×				
Without by-pass cooling system	×				
Plastic intake manifold	×	×			
Engine layout with exhaust components at rear	×	×	×		
Exhaust manifold made of stainless-steel pipes	×	×	×		
Minute-particle fuel injectors			×		
EGR valve driven by high-precision stepper motor (variants for Japan only)		×	×		
Long-reach spark plugs		×			
Low-viscosity (0W20) oil (variants for Japan only)		×			

means of minimizing weight and bulk, so they were comprehensively effected in combination with each other. With regard to materials, the cylinder block is made of aluminum; the cylinder-head cover and intake manifold are made of plastic; the exhaust manifold has a pipe-based structure and driven by a timing chain. Component integration was applied in many areas of the engine. Notably, the functions of engine accessories were integrated into the cylinder block.

Compared with an earlier 1.5-liter engine, the new 1.5-liter variant is 36 mm smaller in terms of overall length, approximately 30 kg lighter, and has approximately 20 % fewer parts. These benefits help to maximize possibilities for customers to enjoy innovative vehicle design, abundant interior spaciousness, and superior performance and handling.

2.2 High output and low fuel consumption

A Mitsubishi Innovative Valve timing Electronic Control (MIVEC) system and other measures (including optimized shaping of the intake and exhaust manifolds and cylinder head) promote intake and exhaust efficiency. Optimally shaped cooling passages in the cylinder head and optimal control of the flow of coolant into the cylinder head help to suppress knocking. And major components reflect comprehensive measures to minimize friction. As a result, each engine variant offers best-in class output and fuel economy. Figures on performance and fuel economy are shown in **Table 2**.

2.3 Low exhaust emissions

Exhaust emissions from the engine are minimized by measures including optimal design of the combustion chambers, optimal control of the intake air motion by means of the cylinder-head ports, employment of the MIVEC system, employment of an ultra-thin cylinder-head gasket, and employment of micro-droplet fuel injectors. The vehicle's overall exhaust emissions are further suppressed by location of the exhaust manifold at the rear of the engine. This layout is beneficial since it minimizes the heat capacity of the exhaust system upstream of the catalytic converter and thus, together with combustion control, promotes activation of the catalytic converter.

With each engine variant for Europe, a single underfloor catalytic converter enables compliance with the EURO4 emission regulations. In two-wheel-drive (2WD) vehicles for Japan, each engine variant achieves emission levels 75 % lower than those permitted by Japan's 2005 emission regulations.

3. Major specifications

Major specifications are shown in **Table 3**.

Table 2 Engine performance and vehicle fuel economy

<table>
<tr><th rowspan="2">Item \ Displacement</th><th colspan="3">Variants for Europe:
All figures for variants for Europe were obtained using premium unleaded gasoline.
(Fuel-economy figures of variants for Europe were obtained with manual transmission.)</th><th colspan="2">Variants for Japan:
All figures for variants for Japan were obtained using regular unleaded gasoline.
(Fuel-economy figures of variants for Japan correspond to 2WD vehicles.)</th></tr>
<tr><th>1.1 L</th><th>1.3 L</th><th>1.5 L</th><th>1.3 L</th><th>1.5 L</th></tr>
<tr><td>Maximum output (kW/min^{-1})</td><td>55/6,000</td><td>70/6,000</td><td>80/6,000</td><td>68/6,000</td><td>77/6,000</td></tr>
<tr><td>Maximum torque (Nm/min^{-1})</td><td>100/3,500</td><td>125/4,000</td><td>145/4,000</td><td>124/4,000</td><td>141/4,000</td></tr>
<tr><td>New European mode fuel consumption (L/100 km)/
equivalent inertia weight (kg)</td><td>5.5/1,020</td><td>5.8/1,020</td><td>6.2/1,130</td><td colspan="2">–</td></tr>
<tr><td>10·15-mode fuel economy (km/L)/equivalent inertia weight (kg)</td><td colspan="3">–</td><td>20.5/1,000</td><td>18.2/1,250</td></tr>
</table>

Table 3 Major specifications

<table>
<tr><th colspan="2">Item \ Displacement (model)</th><th>1.1 L (3A91)</th><th>1.3 L (4A90)</th><th>1.5 L (4A91)</th></tr>
<tr><td colspan="2">Displacement (L)</td><td>1.124</td><td>1.332</td><td>1.499</td></tr>
<tr><td colspan="2">Cylinder bore pitch (mm)</td><td colspan="3">83</td></tr>
<tr><td colspan="2">Cylinder bore diameter (mm)</td><td colspan="3">75</td></tr>
<tr><td colspan="2">Stroke (mm)</td><td>84.8</td><td>75.4</td><td>84.8</td></tr>
<tr><td colspan="2">Connecting rod length (mm)</td><td>140.6</td><td>128.3</td><td>140.6</td></tr>
<tr><td colspan="2">Valve diameter (mm)</td><td colspan="3">IN: 30.5 / EX: 25.5</td></tr>
<tr><td colspan="2">Compression ratio
(with premium gasoline for Europe; with regular gasoline for Japan)</td><td>10.5/–</td><td>10.5/10.5</td><td>10.5/10.0</td></tr>
<tr><td colspan="2">Cylinder block material</td><td colspan="3">Die-cast aluminum</td></tr>
<tr><td colspan="2">Valve mechanism</td><td colspan="3">DOHC; 4 valves per cylinder; directly actuated valves + MIVEC system</td></tr>
<tr><td colspan="2">Camshaft drive arrangement</td><td colspan="3">Roller chain</td></tr>
<tr><td colspan="2">Balancer shaft</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td colspan="2">Fuel control method</td><td colspan="3">Speed density</td></tr>
<tr><td colspan="2">Engine alignment</td><td colspan="3">Rear exhaust</td></tr>
<tr><td rowspan="2">Exhaust emission regulation compliance</td><td>Europe</td><td colspan="3">EURO4</td></tr>
<tr><td>Japan</td><td>–</td><td colspan="2">Emission levels 75 % lower than those permitted by Japan's 2005 emission regulations (4☆)*1</td></tr>
<tr><td colspan="2">Engine overall length*2 *3 (mm)</td><td>357</td><td colspan="2">440</td></tr>
<tr><td colspan="2">Engine dry weight*3 (kg)</td><td>76</td><td>82</td><td>85</td></tr>
</table>

*1: 2WD vehicles only
*2: From end surface of crankshaft pulley to rearmost surface of cylinder block
*3: Engine main body only (configuration for 5-speed manual transmission) (excluding body-mounted components)

(Engine Designing Department, Development Engineering Center: Hasegawa, Miyamoto)

eK·ACTIVE

Following the standard eK·WAGON, the more athletic eK·SPORT, and the refined eK·CLASSY, the eK·ACTIVE is the fourth model in Mitsubishi's eK series. Reflecting the concept of "cheerful all-round mini wagon", it inherits the technological merits of the other eK models while bringing a touch of Sports Utility Vehicle (SUV) styling – a key element of Mitsubishi's DNA – to the minicar class. It went on sale on May 25, 2004.

1. Targets

The eK·ACTIVE is aimed mainly at married men and women in their thirties who are fashion-conscious, have a strong sense of individuality, and are youthful in their outlook. It reflects a goal of creating a model with performance that's valuable not only around town but also for sports and leisure activities; a model that expands the limits of minicar usability. By introducing the eK·ACTIVE, moreover, Mitsubishi Motors Corporation (MMC) successfully sought to expand overall sales of the eK series by increasing the appeal of the series to a more comprehensive range of customers.

2. Features

(1) SUV-like packaging

In line with the principle that the high seating positions of an SUV give good visibility, the eK·ACTIVE has a seat height that yields a 45 mm higher hip point (and concomitantly superior all-round visibility) while permitting users to step into the cabin in a more natural position and with minimal vertical movement of their lower backs.

Further, large, 165/60R14 tires give 10 mm greater ground clearance, permitting easy driving even over moderately uneven surfaces.

(2) Tough, endearing exterior design

In the exterior styling, a protector-style design around the bottom of the body conveys SUV-like toughness and functional elegance. Seven-spoke aluminum wheels with a design unique to the eK·ACTIVE further hint at underlying strength. At the same time, features such as solidly shaped headlights and circle-motif rear combination lamps create an endearing minicar look.

The body has SUV-style two-tone coloring that's ideally matched to both town and country. There's a range of seven upper-body colors and a range of three lower-body colors, which are coordinated with the upper-body colors. Mitsubishi's theme color for the eK·ACTIVE is light green mica.

(3) Casual, refined interior design

In the cabin, a rhythmical two-tone color scheme with dark blue accents on a light gray keynote color creates a casual but refined environment that conveys a feeling of fun.

The seat design combines superior functionality with a unique look; each seat has smooth, lightly textured, light gray fabric, which conveys a sense of sportiness, on its main surfaces and dark blue jersey fabric, which resembles protector patches, on its edges.

(4) Strong powertrain

The powertrain is based on that of the eK·SPORT; it consists of the 3G83 inline three-cylinder engine with intercooled turbocharger, which has earned praise for its powerful response, and a four-speed automatic transmission. It incorporates a number of refinements for the eK·ACTIVE. These include a low-friction treatment for the toothed side of the timing belt (this realizes quieter operation) and a high-density catalyst (this enables the eK·ACTIVE to qualify for 2005 exhaust gas standard 50 % reduction level 3☆). The overall result is powerful, refined, environmentally responsible performance (VT grade). The eK·ACTIVE is also available with a naturally aspirated engine with low-emission 3☆ (V grade).

(5) Sure handling stability and a smooth ride

The suspension system has a structure that was already proven in earlier models in the eK series: light, compact MacPherson struts at the front and a 3-link rigid axle with torque arm and coil spring arrangement at the rear. While retaining the advantages of the suspension system used in the eK·SPORT and eK·CLASSY, it is tuned specially for the eK·ACTIVE to give an SUV-like ride that combines stability with suppleness and does not feel unduly hard.

As with the eK·SPORT, reinforced suspension strut mountings and strong joints between the trailingarm brackets and side sills contribute to superior body stiffness. And as with the eK·CLASSY, low-friction, high-response valves in the front struts and backside multi-layer valves in the rear shock absorbers realize a flat, refined ride feel. Further, a double-pillow-ball-joint front stabilizer with the thickest wire diameter in the eK series is combined with specially tuned strut damping rates and spring constants to realize cornering stability with minimal roll (notwithstanding the vehicle's relative height) and to realize natural overall handling that's faithful to the driver's intentions.

(6) Abundant functionality and comfort

A full range of functional features that are unique to the eK·ACTIVE make this model an SUV that owners can truly enjoy driving with their families and friends.

Built-in roof rails are standard equipment. An aero-type design combining aluminum and plastic makes them visually consistent with the body and gives them good aerodynamic characteristics.

The rear seat has a large center armrest that incorporates cupholders. (These features apply to the VT grade.) Location of the cupholders in the middle of the rear seat realizes convenience for rear-seat passengers.

High-intensity-discharge (HID) headlights are optionally available. With a twin-bulb design (the first of its kind to be used on a Mitsubishi minicar), they offer HID brightness for the high and low beams.

Heated door mirrors, which demist themselves to ensure superior visibility in harsh environments, are standard equipment for cold regions.

Other features (not exclusive to the eK·ACTIVE) are adopted from other models in the eK series for superior convenience and comfort. These include an automatic air conditioner (offered in the VT grade; the first of its kind to be used on a Mitsubishi minicar, in the eK·CLASSY); ultraviolet- and infrared-cutting window glass that minimizes the burning sensation on the skin that can be experienced in strong sunshine; and an Electronic Time & Alarm Control system, which effects centralized control over power-window anti-pinch mechanisms, a headlight auto-off function, and other functions.

3. Major specifications

Major specifications are shown in the following table.

Specifications \ Model				eK·ACTIVE			
				VT		V	
				2WD	4WD	2WD	4WD
				4 A/T			
Dimensions	Overall length		(mm)	3,395			
	Overall width		(mm)	1,475			
	Overall height		(mm)	1,600			
	Wheelbase		(mm)	2,340			
	Tread	Front	(mm)	1,295			
		Rear	(mm)	1,295			
	Interior length		(mm)	1,830			
	Interior width		(mm)	1,220			
	Interior height		(mm)	1,280			
	Vehicle weight		(kg)	860	910	840	890
	Minimum turning radius		(m)	4.6			
Engine	Model			3G83 with intercooled turbocharger		3G83	
	Displacement		(cc)	657			
	Valve mechanism; number of cylinders			SOHC 12 valves; 3 cylinders			
	Maximum output		{kW (PS)/min^{-1} net}	47 (64)/6,000		37 (50)/6,500	
	Maximum torque		{NM (kgf·m)/min^{-1} net}	93 (9.5)/3,500		62 (6.3)/4,000	
	Fuel supply system			ECI-MULTI (electronically controlled fuel injection)			
Chassis	Steering			Rack and pinion (with power assistance)			
	Suspension	Front		MacPherson struts			
		Rear		3-link rigid axle with torque arm			
	Brakes	Front		Ventilated discs (14-inch)		Discs (13-inch)	
		Rear		Leading/trailing drums (7-inch)			
	Tires			165/60R14			

(Mini Car Product Development Project, Product Development Office: Fukuchi, Nishino, Ohhashi)

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