Assimilation and Evolution of Basic Technologies: Weight Reduction of Automobile Parts

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This paper describes weight reducing technology for automotive parts in order to reduce CO_2 and improve fuel consumption of automobiles in response to environment problems. It also explains the importance of basic technologies (material development, measurement and simulation analysis, efficiency technology, and manufacturing technology) and the need for future research, using examples of developed technologies, both directly and indirectly related the weight reduction.

Key Words: *weight reduction, basic technology, material substitution, measurement, simulation, efficiency technology, manufacturing technology*

1. Introduction

Together with raising awareness about sustainability, we greet a great turning point in energy and automobile-related industries concurrent with the radical changes in the environment surrounding automobiles. It would appear that we evolve from the vehicles to the mobility, then from simply moving and means of transportation to things such as the creation of greater values, including services. Furthermore, the rapid growth of developing countries is intensifying competition across all industries, making it a necessity to create new ideas for technological innovations that defy the successful experiences and common knowledge of the past [1].

In the midst of these circumstances, at the research and development field at JTEKT is mainly working on the development of fundamental element technologies with the aim of improving product competitiveness of current business products, and pursuing the creation of novel technologies for new domain. This report introduces examples of the efforts of fundamental research concerning the environmental friendliness of automobile parts within the direction of automobiles, focusing in particular on weight reduction.

2. Improvements in Energy and Fuel Consumption for Environmental Friendliness

As an environmental problem, global warming stands in an extremely important position, together with natural resource and energy issues. In an effort to reduce the amount of the global warming factor CO_2, there exist worldwide reduction goals for automobiles (**Fig. 1**) [2], and

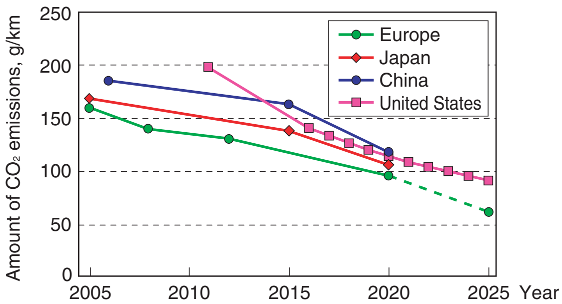

Fig. 1 Trends of fuel efficiency regulation (amount of CO_2 emission)[2]

developments in fuel consumption improvement alike are intensifying within automobile parts as well.

Recently, with advancements in electronization as seen in EV and HEV automobiles, deceleration energy recovery and idling stop mechanisms, and with downsizing from the development of next-generation internal combustion and the shift to small emissions (with superchargers), fuel consumption has improved drastically. It can be expected that the rate of cars equipped with such devices will continue to increase.

Efforts by JTEKT to switch from hydraulic power steering to electric power steering (EPS) have led to a fuel consumption improvement of approximately 3% (in small-size automobiles). In addition, motor size reduction, harness curtailment and the utilization of aluminum columns have achieved weight reduction of approximately 15% (**Fig. 2**). Electronically controlled 4WD coupling has also led to approximately 38% reduction in weight, and consumed energy was reduced by 47% due to the 30% size reduction of the motor, using a 2012 mass-produced electronic oil pump for idling stop [3]. The achievement of these results forms the background for the accumulation of technologies through the fusion and evolution of cultivated fundamental technologies.

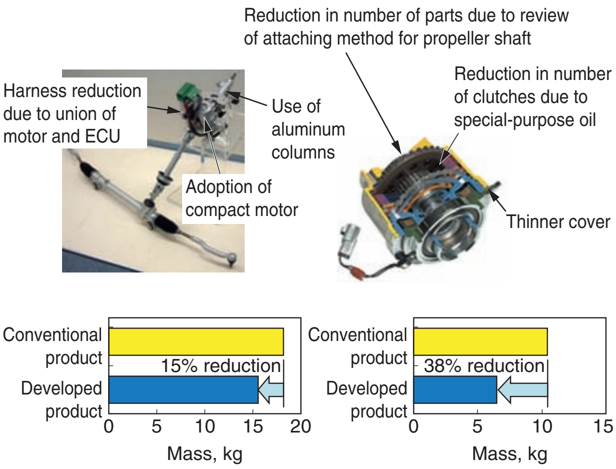

Fig. 2 Examples of weight reduction efforts[3]

3. Approach to Fundamental Technology R&D for Weight Reduction

We have summarized the general outline of efforts for improving fuel consumption in **Fig. 3**. Most important are 1) technologies for improving efficacy in power trains and drive trains, 2) technologies for improving efficacy in energy input and output for the whole vehicle, and 3) weight reduction technologies for decreasing mass. In this report, we will discuss approaches for fundamental technology research as well as its direction, covering 3) in particular.

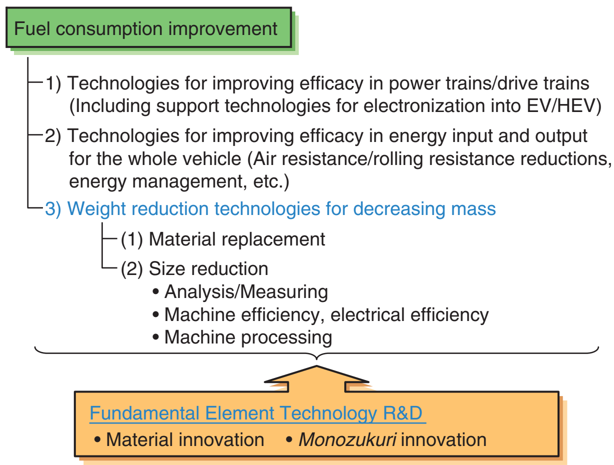

Fig. 3 Outline of the approach to improve fuel consumption

As shown in **Fig. 4**, there is an inversely proportionate tendency between automobile mass and fuel consumption, and weight reduction is effective in improving fuel consumption.

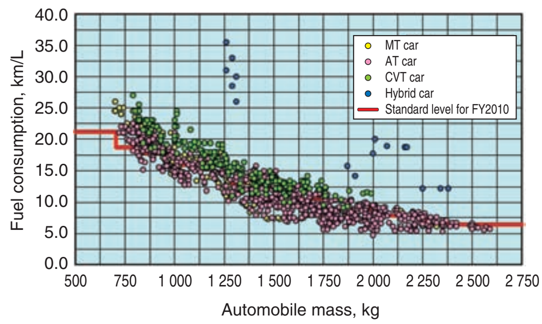

Fig. 4 Relationship between vehicle weight and fuel consumption[4]

Also, with weight reduction, it is understood that there are other performance-related merits besides reduced fuel consumption[5], as shown in **Table 1**. Within automobiles and mobility based on "Run", "Stop", "Turn", mass is an extremely important element in regards to motive ability, and therefore it is necessary to focus particularly on weight reduction technologies. For the formulas expressing rolling resistance in tires, acceleration, braking, and resistance during rotation, each is related to total mass of the automobile, and it can be said that mass has a considerable influence on energy loss.

Table 1 Advantages of weight reduction[5]

Results of the effects of a trial calculation for a passenger vehicle achieving 10% weight reduction at 1 500 kg with a capacity of 5 people

Item		Result
Emission gas	CO	−4.5%
	HC	−2.5%
	NO_X	−8.8%
Fuel consumption performance (10 and 15 mode)		−3.8%
Starting acceleration performance		+8%
Brake stopping distance		−5%
Comfort (Steering effort at micro-low speeds)		+6%
Durability (Fatigue strength leading to cracks)		+70%

Fundamental technologies directly and indirectly related to weight reduction will be discussed below.

3. 1 Material Replacement

Material replacement is the most directly effective method for weight reduction. The replacement of iron with aluminum and resin has been steadily increasing and expanding. Efforts to change to resin for weight reduction has been quicker than those for aluminum, a tendency which has accelerated in recent years. Resin holds high marks in recyclability, but the problem is how to accommodate its differences with iron in strength, durability, rigidity, heat and thermal shock resistance, dimension stability, and age-related deterioration, etc. This makes fundamental technologies such as those for physical property analysis, analysis and measuring, and forming and machining very important. For example, while partially resin parts for the steering gear box are mass produced, as structural components that undergo mounting to the inside of the engine room and receive rack thrust, ensuring reliability against the above-mentioned issues has become a developmental point. Due to this, the change to aluminum has been advancing from early on.

Peripheral technologies have been progressing recently, and like automobiles, the anticipation for magnesium within these technologies is increasing, and attention is being drawn to new materials such as FRP [4]. However, cost, including manufacturing processes, is essential in proceeding with material replacement, and more research and development is expected for balancing weight reduction with cost.

3. 2 Size Reduction

When pursuing size reduction, simply thinning the housing is not enough. It is difficult to achieve large-scale reduction in size without reviewing basic design, such as combined unification of housing components. This requires stress analysis and measuring technologies for ensuring strength, as well as analysis and evaluation technologies concerning friction and abrasion within the field of tribology, and energy analysis technologies within the field of electricity. Technology from new machining methods is also necessary for improving shape generation and accuracy.

Examples of research details of these fundamental technologies are introduced below [6-13].

3. 2. 1 Analysis and Measuring

As with material replacement, shape changes such as size reduction and thinning generally employ stress distribution and thermal displacement in regular FEM analysis, distortion, review of natural vibration, and the processes of design, trial production and evaluation. Depending on how accurate actual phenomena are perceived to be, the influence from development may be large.

Stress measurement generally involves the use of a stress gauge, but in this research we have developed a new method of measurement which specifies the largest stress generated within structural components, as well as the place of generation. This contributes to product size reduction by providing feedback of the results to the analysis model. An example of this technology applied to the constant velocity joint (CVJ) of a power train system is shown in **Fig. 5** [6].

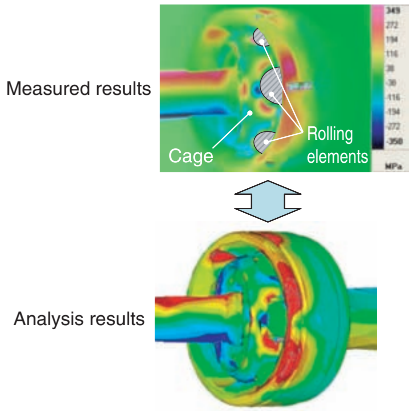

Fig. 5 Example of stress distribution measurement using infrared

The CVJ has been given even greater high-accuracy calculation ability due to enabled visualization of stress distribution inside the joint. Thus, the newly-developed compact CVJ achieves 300 to 900 g in weight reduction for a single vehicle. Also, when applied to the steering intermediate shaft, this technology adds the influence of coupled force generated by the mounting state of the vehicle, enabling the calculation of the internal stress distribution inside the slide mechanism part.

3. 2. 2 Machine Efficiency

Raising energy efficiency leads directly to the improvement of automobile fuel efficiency, and enables plans for the size reduction of the improved component through efficiency improvements in unit devices.

Losses caused by gear meshing and friction within the gear and sliding part of the unit devices greatly affect machine efficiency, to which there are tribological contributing factors.

We have focused on reducing friction in the bearings most used within automobiles, based on elastohydrodynamic lubrication (EHL) and analysis of factors in friction generation, and promote streamlining and the reduction of friction torque through independent technologies. We must also consider decreases in strength and rigidity, etc. for the compaction of the bearings themselves. Though these are difficult points, reducing friction reduces the required output for the output power of unit devices such as the motor, and this may lead to the compaction of output devices equivalent to this reduction. As an example, we have achieved large-scale friction reduction in tapered roller bearings by clarifying the relationship of friction resistance to all parameters and through optimization of all contradicting characteristics. (**Fig. 6**).

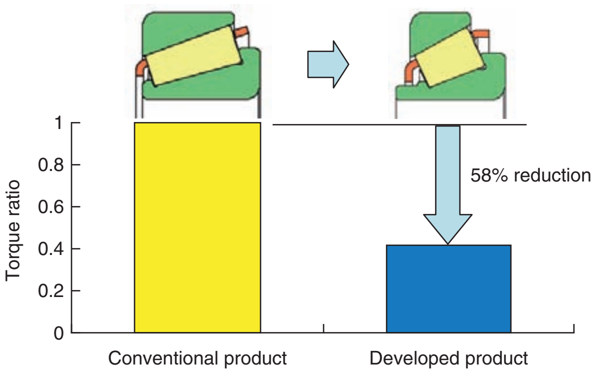

Fig. 6 Reduction of tapered roller bearing friction torque through parameter optimization[7)]

We also conducted the development of grease to balance the reduced resistance in sliding parts of the unit devices with improvements of damping characteristics for silencing (**Fig. 7**).

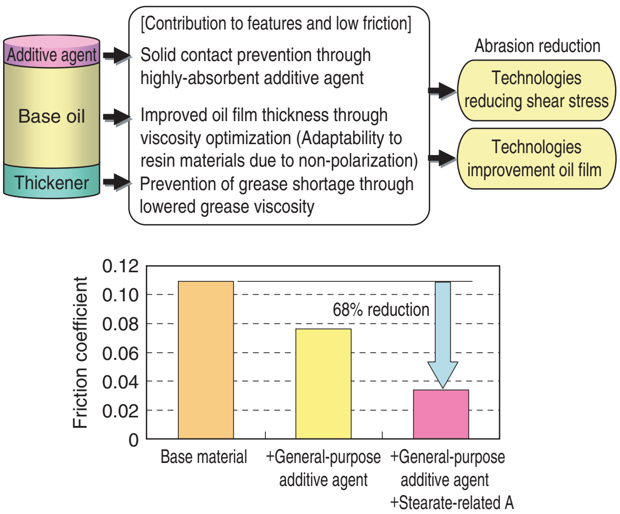

Fig. 7 Low-friction grease[8)]

Another method we have focused on for low friction research involving surface treatment is the improvement and application of the Diamond-like Carbon (DLC) film[9)]. Power train system electronically controlled 4WD coupling (ITCC: Intelligent Torque Controlled Coupling) used in practical application achieved greater size reduction through their low friction characteristics.

For DLC films, we are also contemplating plans to expand automobile parts and other components (**Fig. 8**). On the other hand, although we utilize the plasma CVD superior in mass production for forming films, we have also developed a treatment method that further improves mass productiveness with low heat.

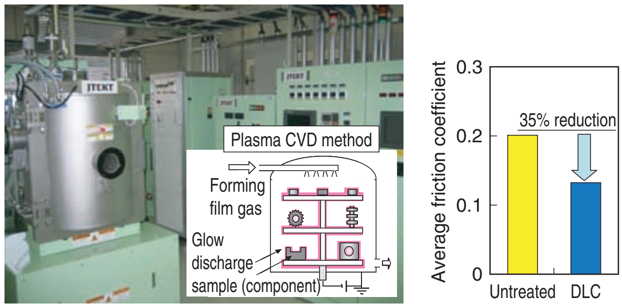

Fig. 8 Friction reduction using DLC films[9)]

3. 2. 3 Electrical Efficiency

Unit devices receive power supply from the battery, and outputs of torque and thrust are generated; however in terms of energy efficiency, the electricity efficiency is as an important factor as the abovementioned machine efficiency. **Figure 9** shows EPS energy loss as an example.

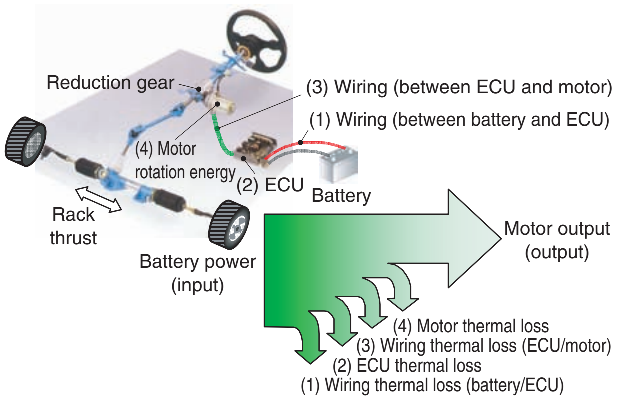

Fig. 9 Energy loss within the EPS system[10)]

Losses from batteries, harnesses, ECU (Electronic Control Unit), motor harnesses, and loss within the motor part influences electricity efficiency, and efficiency is sought for each of these in turn. The standalone ECU and motor were integrated or united into a harnessless structure, contributing to a weight reduction of 35% compared with the conventional motor through magnetic circuit optimization, more efficient coil space factor, and the development of cyclic technologies to raise motor efficiency[10)].

Figure 10 is an example of compaction enabled through overcoming problems by promoting development within production technologies in response to high coil space factor (a main factor in bottlenecking within motor design) and magnetic circuit optimization. This suggests that *monozukuri* innovations within production development hold a vital existence.

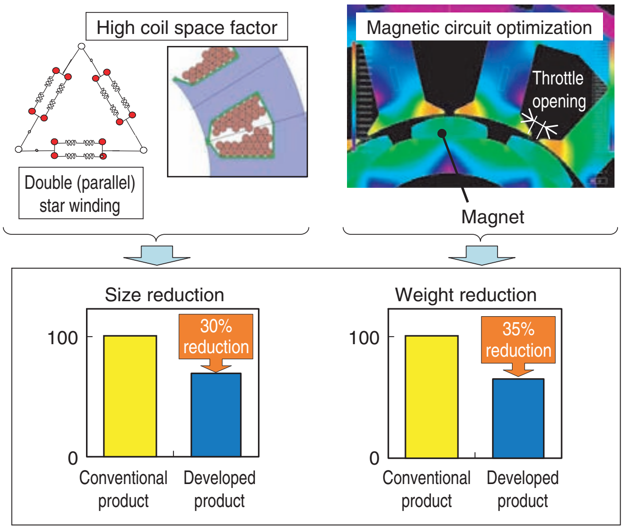

Fig. 10 Case example of motor downsizing/weight reduction[10)]

3. 2. 4 Machine Processing

Within the structures of unit devices, there is the issue that division or thickening must be conducted on parts in accordance with restrictive conditions from tool path, secured accuracy and dispersion reduction within conventional machining methods. In other words, there is the possibility of compaction by applying new machining methods. Our company must leverage our strength as a machine tools maker, promoting the development of parts machining element technology to pave the way to size reduction. For high machining accuracy, we developed technologies that compensate for workpiece heat distortion and deflection amount by improving machine rigidity, and confirmed their results (**Fig. 11, 12**). From here, we will use these confirmed results to create a design feedback loop and capitalize on compact design.

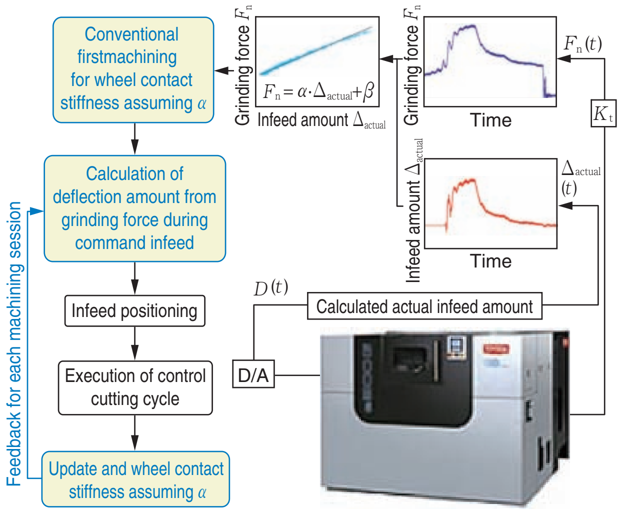

Fig. 11 Feed control based on calculations of workpiece deflection[11)]

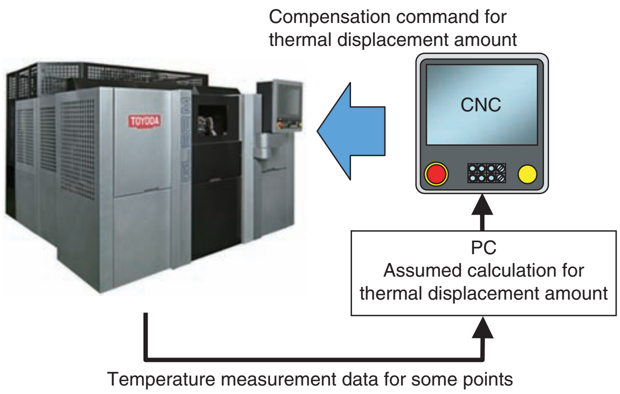

Fig. 12 Thermal deformation compensation[12), 13)]

4. Conclusion

The need for weight reduction will undoubtedly increase further in years to come. In this report, we introduced technology examples both directly and indirectly necessary to weight reduction. On the other hand, cost remains extremely important even if revolutionary weight reduction is achieved, and it goes without saying that balancing these two factors is most important.

Regardless of the framework of not only automobile, but bearings, machine tools and mechatronics operations, research and development matched to the needs and innovative technologies of the customer is vital; created through the fusion and evolution of fundamental technologies such as material development, measuring and analysis, efficient technologies, and production technologies. We wish to connect the achievements of research and development with the improved value of attractive products, while continuing to strengthen the ties between each of our operations headquarters.

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