Application of Flexible Technical Computing Platform to Electrification of Automotive Products

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JTEKT CORPORATION is an automobile parts and machine tools manufacturer that sells steering systems, bearings, and driveline components worldwide that help to improve fuel efficiency. Electrification of these products has been accelerating, and JTEKT has focused on developing technologies to further contribute to compact, lightweight, and high-efficiency vehicles that are even more energy efficient. Electrification of automotive products is also steadily expanding in emerging markets. In particular, there are urgent demands to overcome such technical challenges as developing low-cost and ultra-lightweight electronic components that can operate in harsh conditions. Thus, while ensuring greater reliability in products than that conventionally achieved, JTEKT is working to quickly develop high-performance, highly functional car electronics. To achieve this, it has introduced the Flexible Technical Computing Platform (FTCP), a general design and development environment that utilizes Fujitsu's Engineering Cloud, and is using it to construct its own development platform. This paper introduces the steps taken by JTEKT to construct this platform for use in developing car electronics.

1. Introduction

JTEKT CORPORATION[1)] (hereinafter, JTEKT) is an automobile parts and machine tools manufacturer whose steering systems, bearings, and driveline components help to improve fuel efficiency in automobiles throughout the world. Beginning with its steering systems, which currently have the top market share in the world, JTEKT is accelerating the electrification of these products. It is placing importance on and moving forward with the development of elemental technologies that contribute to small, lightweight, and highly efficient systems with high energy savings.

The trend toward electrification is also gaining momentum in emerging markets. In these markets, there is a particular need to solve high-level technical problems to achieve low-cost and ultra-lightweight products that can operate under severe automobile usage conditions. In this business environment, JTEKT must, of course, ensure a high level of product quality that customers can rely on, but it must also solve the technical problems in the products that it provides.

To ensure an even higher level of reliability in electrical equipment for automobile use (car electronics) and to speed up the development process, JTEKT introduced an integrated design and development environment called Flexible Technical Computing Platform (FTCP) using the Fujitsu Engineering Cloud[2)] and began construction of a new car electronics development platform. FTCP is a design environment that makes full use of Fujitsu core servers and networks and the high level of quality and technology accumulated over many years by several thousand Fujitsu engineers supporting the development of compact technical products. JTEKT's objective here was to add its own original technologies to FTCP and to link those technologies to design analysis tools and parts databases to facilitate the design of high-reliability products. With this design environment, JTEKT is developing products that are highly competitive in terms of both quality and cost while also being compact and lightweight to an extent unmatched in the world.

This paper describes measures that were taken by JTEKT and Fujitsu to improve the results of constructing a car electronics development environment using FTCP.

2. Usage environment of JTEKT products

In car electronics, the steering system (**Figure 1**) ranks as an important component for securing safety considering its role of "turning" the car. The end user of the steering system—the driver—naturally thinks of it as a component that must not break down since its failure could easily lead to an accident.

Recent automobiles enable the driver to turn the steering wheel without having to exert excessive force despite the fact that the weight of the vehicle at close to one ton is applied to the front wheels. This is made possible by a power steering function. There are two main types of power steering: hydraulic power steering and electric power steering. Compared with hydraulic power steering, electric power steering has the advantages of

- an energy-saving design consuming as much as 20% less energy and
- a compact design having no pumps, hoses, etc.

Because of these features, electric power steering is rapidly making inroads into not only developed countries but also emerging markets and countries with severe driving conditions.

In the mounting of car electronics, the general approach is to place electronic parts in as safe an environment as possible within the automobile. For a steering product, however, there is inherently very little freedom in selecting the mounting environment. It is therefore necessary to secure a high level of reliability in an extremely severe environment such as a high-temperature location near the engine or a location in direct contact with water or brine. Conditions that must be given particular consideration in automobiles include temperature, humidity, vibration, moisture, salt content, voltage fluctuation, and surge voltage.

When talking about an automobile's thermal environment, it must be pointed out that the automobile itself is the main heat source. As shown in **Table 1**, the temperature within the engine compartment in the summer time can reach 150˚C at the engine's surface and more

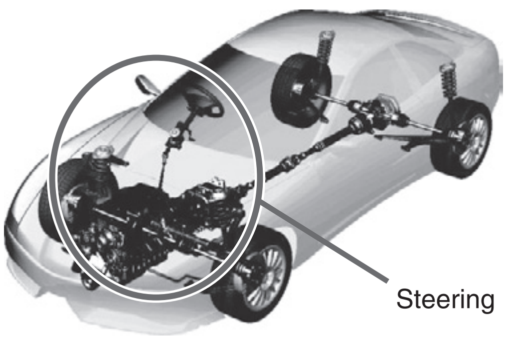

Figure 1
Power steering system.

Table 1
Examples of maximum temperatures at various locations in an automobile.[3)]

Location		Max. temp. (˚C)
Chassis	Nonspecific locations	85
	Near heat source	121
	Oil	175
External car body		121
Engine compartment	Engine surface	150
	Near exhaust pipe	205
	Exhaust manifold	650
Cabin	Floor	85
	Instrument panel: top surface	113
	Instrument panel: other locations	85

than 200˚C near the exhaust pipe.[3] On the other hand, temperatures in the winter time can dip as low as −40˚C in colder regions, so the operation of car electronics must be guaranteed across a wide range of temperatures. There is also a need to deal with high-and-low temperature cycles (daytime and nighttime temperatures) as well as sudden changes in temperature (such as the temperature jump when the engine is started).

Vibration and shock are also important issues for automobiles. For example, running a tire up against a curb can produce a shock of 20 g (where g is the acceleration of gravity [9.8 m/s^2]), which has the potential to deform an iron bracket given the right conditions and part location (**Figure 2**).[4] There are also electrically severe environments in an automobile. Power-supply voltage can easily fluctuate depending on the usage conditions of various types of loads—while 12 V is the norm, it can drop below 8 V or rise to almost 16 V. And to make matters worse, surge voltages as high as 20 kV can be generated when spark plugs ignite, producing inductive noise.[3] Moreover, strong electromagnetic waves emitted from in-vehicle wireless devices, external road heaters, etc. must be tolerated in some way. Furthermore, one cannot specify in what kinds of places in the world a certain automobile may be driven. It may be subjected to salt spray near seashores or exposed to dust elsewhere—a wide variety of conditions must be envisioned.

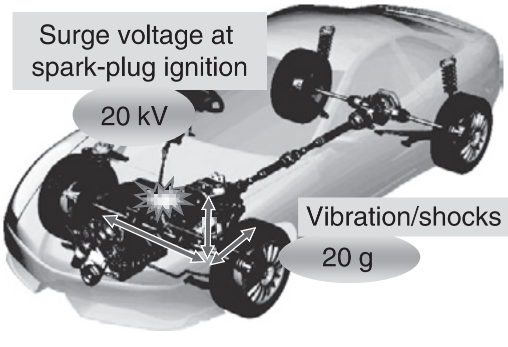

Figure 2
Example of car-electronics usage environment.

Since becoming the first manufacturer in the world to mass produce electric power steering, JTEKT has been conducting reliability evaluations and providing steering products for diverse global environments and automobile usage patterns.

3. Overview of development environment

As described above, a steering system requires very high reliability in a very severe usage environment. But succeeding in a globally competitive market also requires speedy development. To meet these requirements, it is essential to construct a development environment that can shorten development time while enhancing design quality and performance.

It was therefore decided that FTCP, which was originally constructed by Fujitsu for developing its own products, would be used as a basis to which JTEKT could add its own know-how and problem case studies in car electronics development and expand as needed.

FTCP was chosen as a base platform because it provides features that are considered to be essential to a development environment. Specifically, FTCP collects design and production-technology know-how on a single development platform and enables thorough front-end loading from the design stage on the basis of collective knowledge.

At the same time, the three points listed below must be considered when FTCP is applied to car electronics (**Figure 3**).

1) Extension of electronic parts database

Addition of reliability requirements for car electronics

2) Extension of design rules for circuits and circuit boards

Addition of design rules for in-vehicle electronic parts

3) Creation of new functions for achieving coordinated design with electronics manufacturers

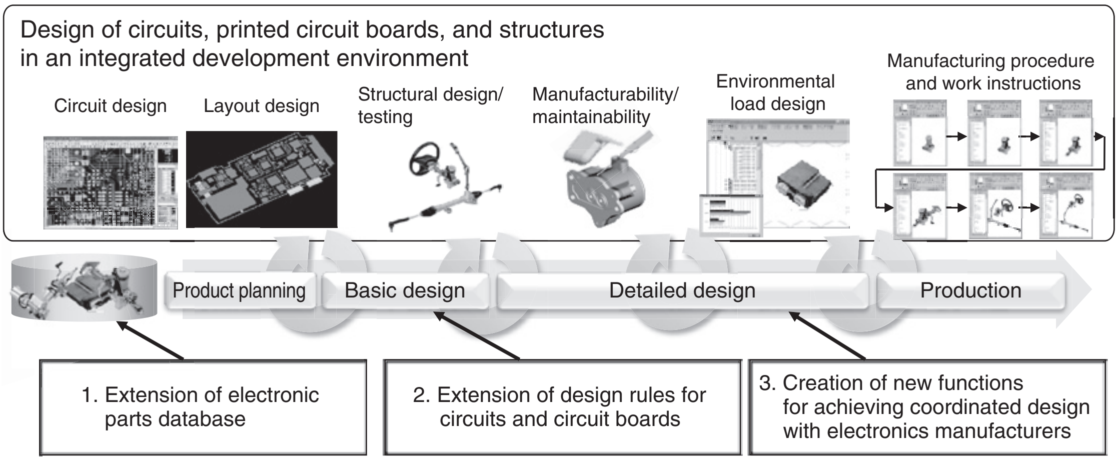

Figure 3
Important points in constructing a development environment.

- Addition of a design testing function that includes cases, motors, and other parts in addition to printed circuit boards
- Addition of a pretesting function to detect problems in facilities and tools including assembly and operations in *monozukuri* (Japanese manufacturing practices)

In the following sections, we introduce the measures taken to address these three points.

4. Extension of electronic parts database

The design and development of car electronics starts by ensuring the quality of electronic parts in a similar manner to that for other electrical equipment. For this reason, JTEKT placed priority on setting up an electronic parts database. In addition to electrical characteristics, an electronic parts database must also store data about mechanical characteristics and material characteristics as well as data associated with procurement and productivity. This is the case with the electronic parts database that Fujitsu has been using, which is why JTEKT was able to apply the FTCP parts database (managed items) directly. However, JTEKT also added and extended reliability requirements for car electronics on the basis of its many years of experience in this field. The related database items that were added include mechanical performance related to vibration and stress, performance related to temperature cycles involving thermal expansion and contraction (in relation, for example, to “tin whiskers”), and environmental performance such as solvent resistance and flame retardation.

In this way, JTEKT added about 30 new items to those already defined by Fujitsu, resulting in the completion of a database having more than 150 managed items per part (**Figure 4**). These added items are intended to be used not only for managing parts but also for designing and testing circuits and printed circuit boards. JTEKT then extended the design rules for circuits and circuit boards and enhanced the functionality of the rule checker.

5. Extension of design rules for circuits and circuit boards

Here, we present a case study on ensuring design quality at the product architecture design stage.

In car electronics, electric power steering is known for its relatively large output (handling maximum currents in excess of 100 A). As a consequence, the heat generated by power steering in the already severe environment of an automobile is creating a problem, and

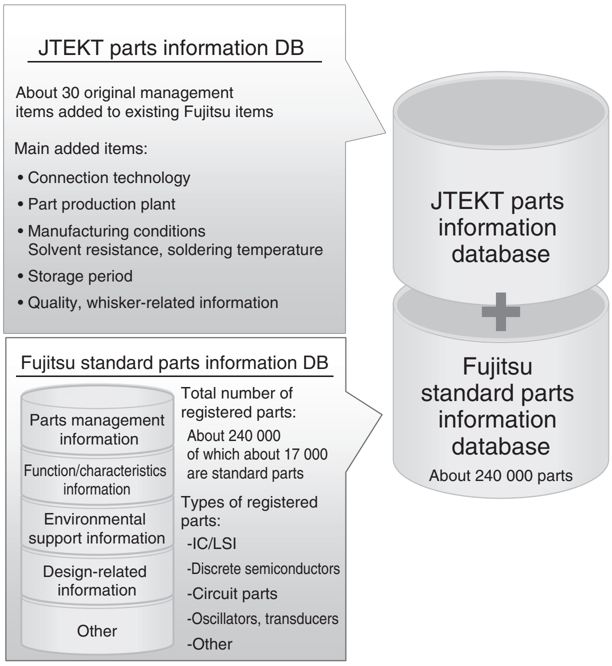

Figure 4
Extension of electronic parts database.

considerable resources including time are being spent to resolve this issue. It is for this reason that a design rule checker has been added to FTCP to reference newly added items in the parts database such as "temperature specifications for each part" and "temperature cycle requirements" and to check whether a problem exists with particular parts with respect to temperature. This design rule checker also takes temperature rises caused by self-heating into account by referring to the results of thermal analysis as another measure to ensure quality at the design stage.

At the same time, electric power steering requires exceptionally high-density mounting of a high-precision sensor, a microcomputer, and an inverter circuit handing large currents. Dealing with the electrical noise generated here requires an advanced problem-solving approach compared with that for ordinary electronic components. With this in mind, JTEKT performed a signal analysis using FTCP, targeting the inverter circuit (the noise source), the sensor circuit (which is easily affected by that noise), and other parts, with the aim of quantifying the inter-wiring clearance needed to prevent crosstalk. As a result of this analysis, the absence of problems in terms of in-house standards was confirmed and a value for minimum clearance was incorporated in the design rules.

Anti-noise design as described above gathers past problem examples from inside the company, quantifies qualitative rules in the defining of design rules, and performs real-time checks during the design process to ensure an appropriate level of anti-noise performance. Using this development environment, JTEKT has been able to design circuits and printed circuit boards having improved anti-noise characteristics without redesign or rework steps while achieving products that are as much as 50% smaller and lighter than past models.

6. Creation of new functions for achieving coordinated design with electronics manufacturers

One policy that JTEKT has established for achieving innovative products that are smaller, lighter, and more efficient for greater energy savings is to develop mechatronics technologies.

Mechatronics technologies are used to integrate electronic-control devices with mechanical parts such as motors and gears with the aim of reducing the number of required parts (making a lighter product), decreasing power-transmission loss (improving electrical efficiency), and improving noise immunity (improving performance). A reduced part count through integration has enabled JTEKT to achieve groundbreaking reductions in size and weight of up to 50% compared with past products.

Mechatronics technologies are thus expected to have a big impact on the future development of all kinds of products. However, their ability to achieve such revolutionary results as 50% reductions in size and weight calls for design and testing techniques different from those used so far for car electronics. The following sections introduce newly developed functions for achieving coordinated design with electronics manufacturers toward the establishment of mechatronics design practices.

6.1 Need for coordinated design between electrical and mechanical products

1) Structure minimization by optimally placing electrical and mechanical products in complicated spaces

Halving the size of a mechatronics unit requires that the dead space between mechanical parts (motors, gears, etc.) be used effectively for incorporating electrical parts.

Securing a neat, box-shaped space between motors and gears that are basically circular in shape is not an easy task. What is needed here are design techniques that can incorporate electrical parts of diverse sizes into complicated spaces that may include curved surfaces while taking electrical performance into account.

2) Structure minimization by taking integrated assembly of electrical and mechanical products into account

The process of manufacturing a mechatronics unit involves the integrated assembly of mechanical and electrical parts. This means that production requirements established for conventional circuit-board manufacturing are not sufficient by themselves. Manufacturing design must also take the assembly of mechanical parts into account to ensure that no problems will arise in processes and manufacturing facilities.

6.2 Functions for achieving coordinated design with electronics manufacturers

The conventional approach of designing electrical and mechanical parts separately can make structure minimization in the case of a mechatronics unit extremely difficult. To address this problem, JTEKT and Fujitsu jointly developed a tool for achieving coordinated design with electronics manufacturers. This tool provides functions for linking electrical-systems computer-aided design (CAD) and mechanical-systems CAD and for performing design testing unique to mechatronics (**Figure 5**).

1) Creation of a circuit integration function and linking with mechanical-systems CAD

In general, a CAD product for electrical systems is configured to perform design work one circuit board at a time. However, design work to minimize the structure of a mechatronics unit is difficult if performed in units of boards. The need was therefore felt for a circuit integration

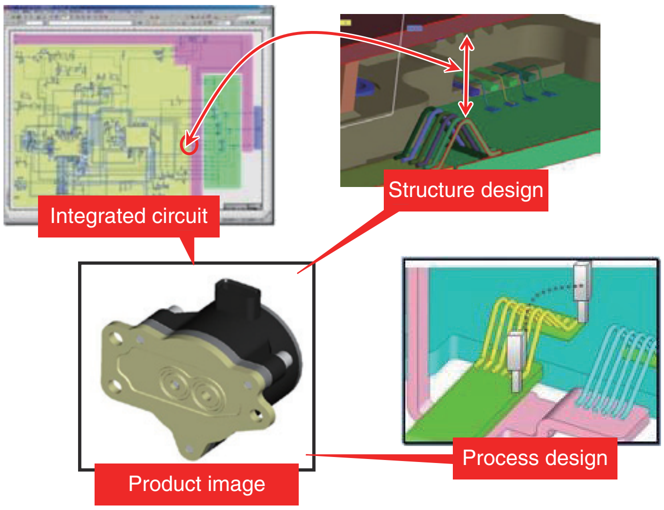

Figure 5
Coordinated design with electronics manufacturers.

function that could handle a mechatronics unit incorporating multiple printed circuit boards and wiring sections as a single circuit. For this purpose, a new function transcending the conventional framework was created.

This circuit integration function is also capable of linking with mechanical-systems CAD and is equipped with the world's first cross-probing testing function between electrical-systems CAD and mechanical-systems CAD.

2) Creation of a design testing function linked with production processes

A design verification test function that takes the integrated assembly of electrical and mechanical parts into account was also created on the basis of the circuit integration function described above. In addition to static analysis for detecting obstructing parts in the assembly process, it was also important that this testing function be able to perform dynamic analysis of jig and tool movements in the manufacturing process. To this end, functional extensions were made to model the size and movement of tools on the basis of actual equipment and to add data on required clearances to design rules. At this time, processes were examined in conjunction with the production technology department.

By performing design verification tests using these functions for coordinating design with electronics manufacturers, JTEKT can achieve high-density, compact designs of mechatronics units—which had been difficult in a conventional design environment—without degrading productivity.

Furthermore, as a result of tools linked with electronics manufacturers being incorporated into the development process as described above, discussions with the production technology department now begin in the initial design stage, which is different from past practices. This type of development environment makes it possible to identify problems that would normally not surface in discussions and development work confined to the design department. As a result, detailed front-end loading can be achieved, which contributes greatly to the prevention of redesign and rework.

7. Conclusion

This paper described how JTEKT established reliability requirements in car electronics and facility/process requirements in its manufacturing line by extending the electronic parts database of the FTCP, extending design rules for circuits and circuit boards, and creating new functions for achieving coordinated design with electronics manufacturers.

Using the technologies presented in this paper to develop ultrasmall, high-reliability, and high-efficiency mechatronics-based units, JTEKT is achieving performance levels that match the needs of the times, thereby boosting the penetration of its products in the car electronics market. JTEKT also aims to expand the use of its mechatronics units to the industrial world in general by making good use of the quality cultivated in its in-vehicle products and is looking to apply its mechatronics know-how to the development of highly functional products with an eye to contributing to the next-generation energy society.

Looking forward, we can envision companies expending considerable effort to ensure quality in their products against a growing trend toward electrification and highly functional systems, and in this regard, we hope that the examples presented in this paper will be of some help in their endeavors.

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