

# Prospects for "Interesting" Development Procedures –Risks and Benefits of Simulation-Riddled Designing–

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*The advance of information technologies has provided various advantages, such as the efficient exchange of technical information. At the same time, negative effects are reported such as a lack of face-to-face communication and in some cases failure to transmit core know-how, which is not fed back by such information technology tools.*

*In product development as well, information technologies, for example computer-aided engineering and computer simulations, contribute to improving efficiency. I would like to quote some examples in current EPS (electric power steering) development and in that respect discuss "pleasant designing work" with computer simulation.*

*At the same time, "interesting" development procedures for engineers should be reconsidered.*

**Key Words:** *information technology, simulation, comfort, pleasure, electric power steering*

## 1. Introduction

In days past, everyone dreamed of owning a car. What was it in those days that made cars so attractive? Wasn't it the fun of carrying out the basic functions of driving, turning and stopping? I believe people have not changed so much since then. The expressions SASAKI provided for car-driving enjoyment are easy to understand. He categorized comfort as the "comfortable enjoyment" of driving and pleasure as the "fun enjoyment" of driving<sup>1)</sup>. MIYAKE defined comfort as the "cheerful feeling" and pleasure as the "pleasant sensation" derived from driving<sup>2)</sup>.

To those who grew up on the manual transmission cars of the 70s, something has been lost in attaining the comfort of today's cars. And we take pleasure in nostalgically pursuing the performance and experience of those times. Such nostalgic pleasures include lifting the hood and maintaining the carburetor, spark plugs, ignition system and timing belt and replacing the tires for example. These were not significant tasks. But there was a certain pleasure that came from sensing performance changes resulting from maintenance work our own hands had done. We understood our cars thoroughly, and when they were not performing well, we could quickly ascertain the cause and perform repairs. Such close understanding of car mechanisms spawned a pleasurable feeling of oneness with them. Unfortunately, these days it is extremely rare to see car enthusiasts lifting the hoods of their cars to show one another the engine compartment.

In regard to the development and design of automotive

components, we can say a similar change is occurring. Today's engineers, even with limited experience in product manufacturing and design, can carry out product design with the "perfect toolbox" given in the form of simulation tools and modeling software. They can order prototypes based on the resultant drawings and even request performance tests. (In the past "nostalgic" days, engineers carrying out new product design had to go around to every department themselves.)

Such an engineer cannot achieve the target performance completely yet cannot specify immediately what the problem is. The deadline is approaching, and therefore he turns to a "tuning specialist," a fellow engineer who based on extensive experience knows how to achieve the performance requirements. His work is similar to applying make-up, sometimes just enough to cover a blemish, sometimes an entire mask. In any case, the tuning specialist can be relied upon to do a good job specifically tailored for the vehicle or application. The problem is that such specialists have difficulty transferring their know-how to younger engineers. Their techniques are not theoretically based or universally applicable for achieving technical values and clarifying root causes.

Today, we can say the pleasure that should motivate engineers engaged in R&D work is being hidden by "simulation" and kept at a distance by "tuning technology." The development toolbox designed to bring comfort to engineers keeps them from attaining maturity, making them so-called "black box engineers" (they open the lid, and never know the inside). One reason for this is the belief in simulation as an almighty design tool of the

baby boomers leading today's age.

In this paper, the pleasure that should accompany development work will be discussed.

## 2. Design by Convenient Tools such as CAE or Simulation

Advances in computers and software have made complex simulations popular in recent years. Various types of parameter studies and visual displays based on these simulations are very useful in demonstrating results clearly and increase persuasiveness. These convenient tools are indispensable for the development and design of many products including steering systems<sup>3)</sup>.

As an example, the development of an electric power steering (EPS) system (Fig. 1) will be discussed, in which case steering torque assistance is provided to the driver by means of an electric motor. (Regarding EPS, while a certain system may provide excellent steering feeling on one vehicle model, it may provide a completely different feeling on another. Steering maneuvering performance is affected by the tires, suspension and other steering-related systems, but this will not be discussed herein due to a lack of space.)

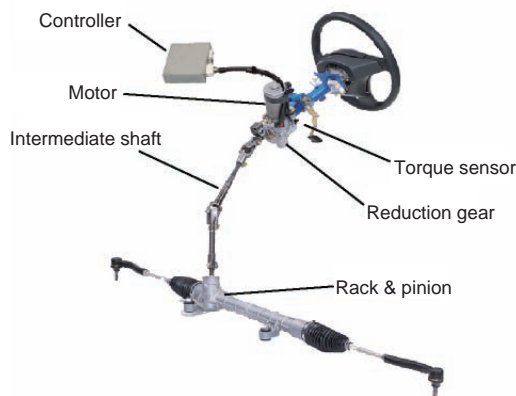


Fig. 1 Electric power steering (EPS) system

Figure 2 shows a control block diagram for EPS. The torque sensor detects torque that the driver has applied to the steering wheel. Motor current corresponding to the detected torque value is calculated and controlled by the electronic control unit (Fig. 3). Figure 4 shows the modeling example of this system.

In actual development work, a model of each element is estimated based on detailed data of an existing design with some modification. Control parameters are decided based on simulation using this model. However, when an EPS system based on CAD drawings created from this design is manufactured and installed in the vehicle, there is no 100% assurance that the predicted performance will be realized.

At this stage a tuning procedure, one advantage of

electronic control systems, is carried out to improve performance. In the case of hydraulic power steering, it is necessary to modify the characteristics of mechanical components such as the control valve to achieve this tuning. Such modifications required logical countermeasures involving design, testing, production engineering, and manufacturing. However, in the case of EPS, assist torque characteristics can be modified instantly using a PC, and repeated simulations comparing various parameters can be carried out freely. As a result, the target performance often can be found by trial-and-error tuning.

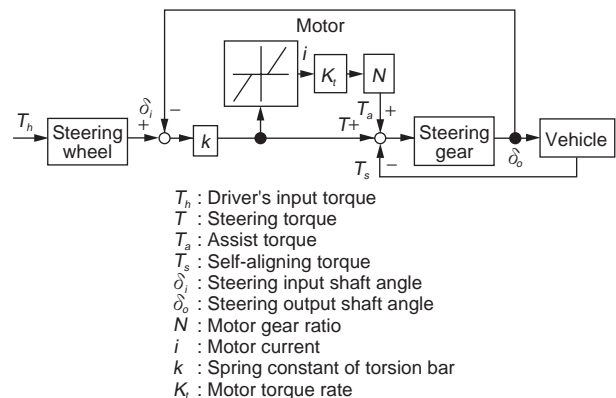


Fig. 2 Basic control block diagram for EPS

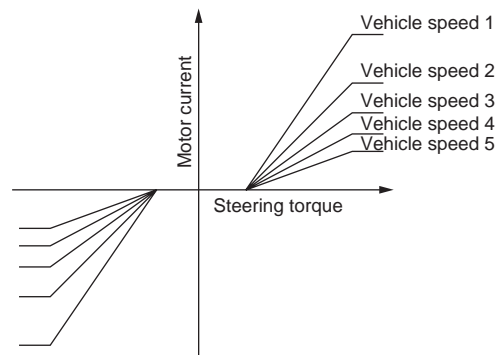
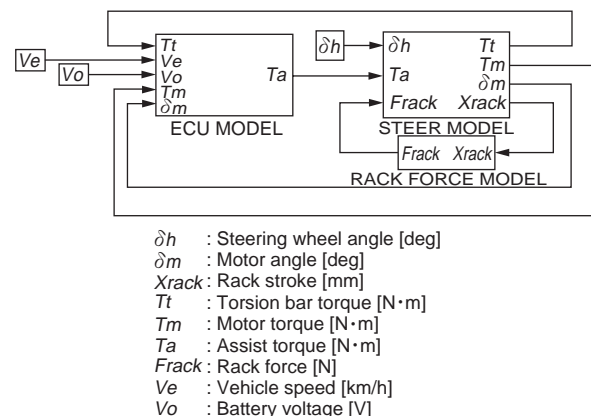


Fig. 3 Characteristics of steering torque and motor current (torque control diagram)



- $\delta_h$  : Steering wheel angle [deg]
- $\delta_m$  : Motor angle [deg]
- $X_{rack}$  : Rack stroke [mm]
- $T_t$  : Torsion bar torque [N·m]
- $T_m$  : Motor torque [N·m]
- $T_a$  : Assist torque [N·m]
- $F_{rack}$  : Rack force [N]
- $V_e$  : Vehicle speed [km/h]
- $V_o$  : Battery voltage [V]

Fig. 4 EPS simulation model

For example, there is a need for performance compensation to offset poor feeling caused by the motor's mechanical inertia. For this purpose, such measures as a compensatory control method to add extra current corresponding to steering speed have been commercially adopted<sup>4),5)</sup>.

Such EPS compensatory control methods have come to be utilized greatly as a result of shrinking vehicle tuning lead times. As a result, compensatory control is sometimes used as a sort of "make-up" and leads, for example, to insufficient response around the neutral zone. However, in the case that analysis based on theory is not clarified, performance adjustment based on parameter settings considered to be suitable is carried out. Further, there are examples such as applying additional current in the steering direction in order to compensate the effect of friction. Such "make-up" control software is spreading and increasingly becoming a "black box" whose details are difficult to understand.

The result is that when one "looks under the hood" of steering technology, the fundamental characteristics of mechanical components and electronic hardware are hidden and cannot be seen. Even if we analyze the steering system on an actual vehicle, the root causes of problems are difficult to ascertain. Moreover, engineering responsibilities within the company have been finely divided. Engineers cannot become involved with components for which they are not responsible, and even those in charge of development cannot evaluate system performance. Such a development system creates engineers deprived of motivation to achieve overall better performance and who are convinced that "comfort" in a development system is ideal.

### 3. Development with "the Hood Open"

Originally, a main focus in EPS development was reducing the amount of steering effort required in parking situations, etc. To achieve this, the generation of sufficient assist torque was a top priority. For that purpose, the combination of a worm gear, which has a simple structure and can easily obtain a high gear ratio, and a high-rotation motor, which has high output, was selected. The disadvantages of this structure, however, are an increase in moment of inertia originating in the high gear ratio and an increase in friction resistance originating in the worm reducer<sup>6)</sup>.

Theoretically, motor torque increases in proportion to the current value, and when current is applied, the motor starts to rotate. However, actual motors have internal mechanical friction, creating a zone in which the motor does not rotate even when current is supplied.

The torque sensor measures torque based on the twisting displacement of an elastic metal part called the

torsion bar. However, there are many cases in which the twisting, play, and gaps of parts other than the torsion bar are not taken into account. For example in regard to the intermediate shaft (I/S) of a column-type EPS (C-EPS<sup>®</sup>) system, whose motor is attached to the column area, the I/S twisting angle can be up to about one-third of the torsion bar. Such displacements have the potential to cause reversed phase related to the motor's rotational position and assistance direction.

Theoretically, the torque sensor can output voltage based on torque detected anywhere in the range from zero torque to the maximum detectable torque value. However, in reality there is a limit in resolution around the zero-torque area, and therefore in this area it is necessary to avoid assistance in the reverse direction caused by noise, etc. Accordingly, actual mass-production systems must have an area in which current is not supplied to the motor even if torque is detected (this is called the "no effect zone" around the steering neutral area) (Fig. 5).

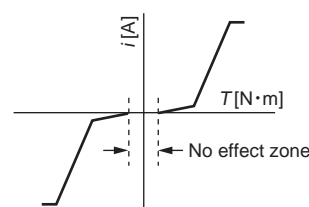


Fig. 5 No effect zone in torque control diagram

In addition, deterioration over time of the mechanical characteristics of element parts should be taken into account, such as changes caused by the worm reducer's high frictional forces. These factors cause problems such as a sticky feeling when the driver starts to turn from a neutral steering angle.

Such factors are not included in simulation models, and the engineer will not see them unless he "looks under the hood." Engineers with limited experience that "lift the hood" cannot understand the content –it is a black box to them– and so they rely on simulation models as a convenient design tool. But by this method, the target performance is not achieved during the initial stage, and to achieve it the engineer must forever rely on tuning procedures, a cycle from which he cannot escape. Consequently, a considerable number of man-hours are required for each vehicle model or application, and although simulation tools should enable the reduction of development man-hours and lead times.

The biggest problem, although not limited to steering systems, is that technology is not transferred to the next generation by inclusion in design standards.

### 4. "Pleasurable" Development

It is necessary to allocate quantitative performance targets for each component in order to achieve the target performance of the vehicle as a consumer product. Targets must be allocated during the design phase not only for steering system element performance but also for system performance. To allocate these performance targets, it is necessary to analyze and classify static and dynamic physical quantities such as friction, elasticity, and inertia and include them in quantitative design requirements. It is essential for engineers involved in design work to understand the upper-level system completely to the point they can explain it by hand calculations. They also must grasp the characteristics of each element sufficiently. For example, steering engineers should understand the actual motor and torque sensor characteristics described earlier herein. And also they should understand the change of worm reducer friction characteristics over time from initial performance through end of life. Of course in order to grasp characteristics accurately, precise testing and measurement of sufficient quantities is necessary even with accelerated testing, and this unavoidably will take work and consume man-hours.

Complete system understanding to the point of being able to explain it by hand calculations and grasping of component characteristics is indispensable to the construction of an excellent system before tuning procedures. If the product's targeted performance is nearly achieved in the initial stage, countermeasures afterward become easy. For tuning procedures, the only work is improving and checking parameters for each vehicle model and ensuring safety coefficients are confirmed, allowing man-hours to be reduced significantly. Also, technology will be transferred to the next generation securely as an excellent design standard. There is no need to create a new design for each vehicle model, and engineers can spend more time on true development work.

Attaining such development capability comes only through hard work and time, but this is more than

compensated for by the pleasure that comes from understanding something inside and out and achieving expected results. This is the pleasure that rightfully should accompany development work. Without this, development work becomes painful, and the engineer seeks escape by adding "comfort" to the process. Therefore it is vital that engineers finding themselves with low interest in their work change their approach in order to discover this pleasure.

An engineer working without this pleasure will not see many important things. This will be verified using the example of two different systems, C-EPS® and rack-direct type EPS (RD-EPS®), installed on the same vehicle. **Figure 6** shows models of the two systems describing elements of elasticity, inertia, and friction.

First, the results of C-EPS® approximate calculations are shown. **Figure 7** shows steering angle vs. steering torque characteristics, representing the function of transferring information by means of force to the driver. **Figure 8** shows an example comparing two types of assist characteristics on a torque control diagram. The feeling from steering torque on the steering wheel can be adjusted like this by tuning of the torque control diagram. This can be adjusted similarly in the cases of both C-EPS® and RD-EPS® as shown in **Fig. 9**.

**Figure 10** shows the steering angle vs. tire angle characteristics for C-EPS® and RD-EPS®. In this case, despite the fact that each element characteristic is assumed to be the same and only the arrangement of components is different, the calculation results for C-EPS® and RD-EPS® are different. In the case of C-EPS®, elasticity elements do not exist between the torsion bar  $K_t$  and the steering wheel, while in the case of RD-EPS®, the intermediate shaft  $K_i$  exists. This shows that the displacement amounts generated by steering torque before the time assist torque is supplied are different. Additionally, in the case of C-EPS®, the assist torque is transmitted to the tires through intermediate shaft  $K_i$  and rack and pinion gear  $K_{rp}$ . In the case of RD-EPS®, the assist torque is directly applied to the rack, and therefore the torque applied to the intermediate shaft  $K_i$  and rack and pinion gear  $K_{rp}$

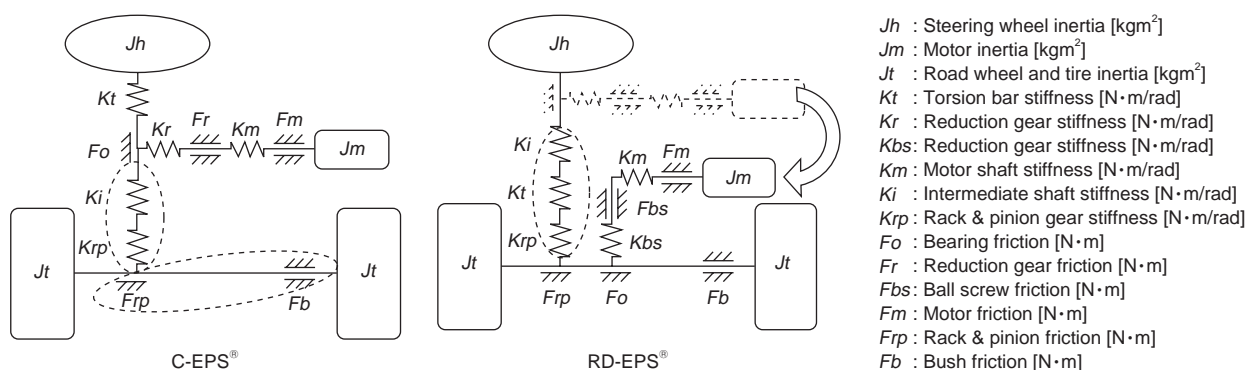
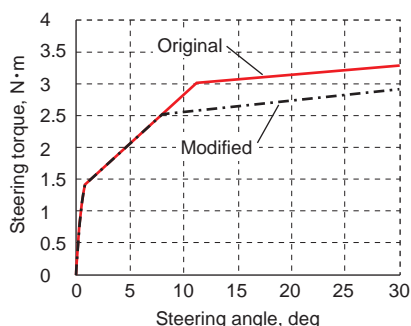
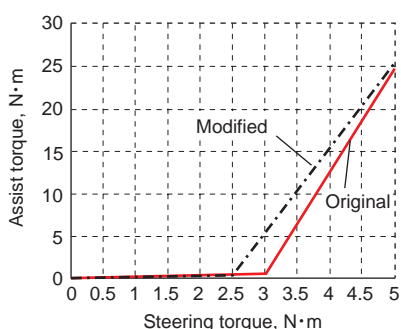


Fig. 6 Structures of C-EPS® and RD-EPS® systems

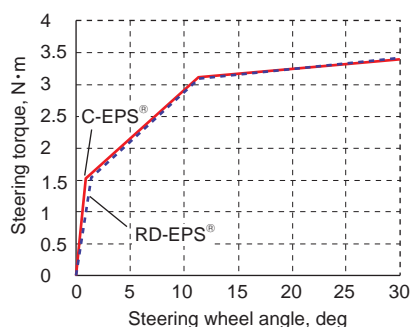
is smaller than in the case of C-EPS<sup>®</sup>. Accordingly, the twisting and flex displacement of intermediate shaft  $K_i$  and rack and pinion gear  $K_{rp}$  is smaller for RD-EPS<sup>®</sup> than for C-EPS<sup>®</sup>. This shows that the element safety coefficient is higher or that a lower rigidity design can be adopted.



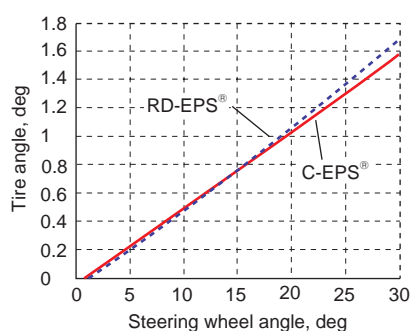
**Fig. 7** Characteristics of steering angle and steering torque



**Fig. 8** Example of modification on torque control diagram



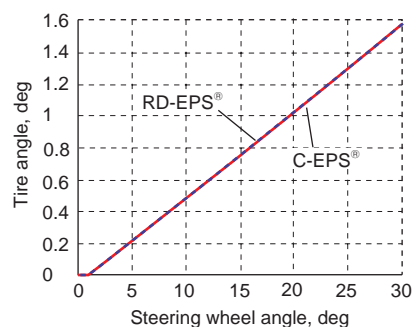
**Fig. 9** Characteristics of steering angle and steering torque



**Fig. 10** Characteristics of steering angle and tire angle

In this case, the driver receives the same feeling from the steering wheel, but due to the difference in steering wheel angle vs. tire angle characteristics, there is a difference in vehicle behavior between C-EPS<sup>®</sup> and RD-EPS<sup>®</sup>. This demonstrates that while modification of the assist torque diagram adjusts the feeling given to the driver, it does not adjust vehicle behavior.

Here, the influence of the arrangement of the previously discussed I/S, rack and pinion gear, etc. and their rigidities are considered. The I/S rigidity is examined and is designed to have a safety coefficient suitable for the applied torque. If this is done, the steering wheel angle vs. tire angle characteristics can be designed (Fig. 11).



**Fig. 11** Characteristics of steering angle and tire angle (system designed)

Next, the case that a rack & pinion hydraulic power steering system installed in a vehicle is replaced with an EPS system is considered. As long as the vehicle characteristics are not greatly changed, the gear's reduction ratio should be kept the same. In the case of pinion-type EPS, however, there is a difference in the amount of torque transmitted through the gear. If a common gear design is used, in the case of EPS, the safety coefficient falls significantly because of the high load. Therefore the tooth surface is modified suitably for the high load and the safety coefficient is supplemented. If a suitable safety coefficient still cannot be obtained, the gear parameters must be revised completely.

In the case of RD-EPS<sup>®</sup>, etc., high load does not exert significant influence on rack and pinion tooth surface strength. With these steering types, however, the dynamic damping characteristics for the high-frequency zone, in the case of hydraulic power steering, that are added to supplement hydraulic system viscosity cannot be added. Even after adding the various mechanical properties of EPS structures (friction, inertia, and time constant), it is self-evident that a design supplementing dynamic characteristics is also necessary.

As these examples show, "lifting the hood" and understanding the contents from corner to corner, i.e. organizing basic system knowledge in one's mind, enables one to see proper system performance design clearly.

In system design and development, it can be said that basic curiosity and the desire to grasp such knowledge by handling parts and assembling them by hand is the first step in this upward spiral toward pleasurable development.

## 5. Conclusion

Japanese traditionally are eager researchers and good at strategic theory, and in 2008, four such researchers won Nobel Prizes. When asked about their efforts, all of them responded, seemingly in chorus, that because they had been engrossed in work they loved, they did not feel it had been toilsome. Likewise, an engineer who loves the design and development work he is involved in does not mind how much time and effort he spends mastering it.

The safety coefficient of each component within a system is calculated based on consideration of the product's usage environment as part of the process to create a reliable design. The process of carrying out testing to verify the design one has created should be a pleasurable experience. Just as 70s car enthusiasts gained pleasure from knowing their cars thoroughly, when the engineer carries out these tasks with deep knowledge gained by his own curiosity, he will have the ability to "do repairs by himself" and will derive a "pleasant sensation" from product development.

Before turning to simulation or modeling tools, engineers should construct models or transfer functions they can be satisfied with using hand calculations. After that, they should make suitable simulation tools by themselves. In such case, they will have convenient, valuable tools that can be commonly used and passed down to the next generation of engineers even if customized.

As systems grow increasingly complex, opportunities to create optimal designs for system components will increase. In that process, it is difficult to believe the future will be bright if supported mainly by tuning technology created to bring "comfort" to development in the form of "comfortably enjoyable" tools and methods.

Recently we have been facing a worldwide economic crisis and dramatic changes in social environments. But one measure a "monozukuri" manufacturer can take during such times is to focus on raising strong engineers, and we should keep in mind that the pleasurable experience of on-the-job training is a fast way to raise such engineers. It is my hope that we can continue deep investigations of theories and principles to lay a deep foundation as a Japanese manufacturer and at the same time pursue development work in a way that produces true pleasure.

## References

- 1) S. Sasaki: Dynamic usability, The Japanese Journal of Ergonomics, (1990) 26.
- 2) S. Miyake: Comfort and experimental technique by physiological measurement, Industry and Science Systems Co., LTD, (2007) 9.
- 3) S. Patrick: KOYO Engineering Journal, 161 (2002) 52.
- 4) M. Tanaka: KOYO Engineering Journal, 155E (1999) 23.
- 5) A. Osuka, Y. Matsuoka, T. Tsutsui, S. Obata, A. Droulers: KOYO Engineering Journal, 161 (2002) 46.
- 6) T. Sugiura: JTEKT Engineering Journal, 1001E (2006) 65.



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