

Creation of a Method for Evaluating Steering Performance

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A prerequisite to taking advantage of the recently developed advanced steering systems and achieving more natural and comfortable steering performance, is the ability to accurately evaluate the qualities of such systems. To this end, we have developed a steering performance evaluation method that focuses on the driver's senses. This method has been utilized in the development of steer-by-wire systems, and we are currently working to expand the evaluation methods for the development of ADAS/ADS.

Key Words: EPS (electric power steering), steering feeling, evaluation method

1. Introduction

More than 30 years have passed since JTEKT was the first in the world to begin mass production of electric power steering (EPS) in 1988. In recent years, vehicles equipped with EPS have accounted for more than 80% of all vehicles¹⁾, and the steering performance and quality required of EPS are continually increasing.

The first EPS was adopted because of the convenience of being able to install it in compact and inexpensive automobiles²⁾. Because the motor control was also relatively simple, the steering feel was inferior to that of a conventional hydraulic power steering (HPS) system. Subsequently, performance was improved by improving the assist mechanism and controls, however more advanced mechanisms and controls made building-in performance more complex, and evaluation of the steering feel depended on the sense and experience of an experienced test driver, making quantitative judgments difficult.

Under these conditions, in order to develop a safer and more secure steering system and deliver a steering feel that is natural and comfortable to the driver, we reviewed the previous evaluation method, and attempted to expand the ranges of the technical and physical approach. These efforts are introduced in this report.

2. Reasons and Policy for Construction of an Evaluation Method

2.1 Previous Evaluation Method

With the JTEKT standard evaluation method, the steering performance test method for vehicles is as shown below.

- Steering feel evaluation test (sensory evaluation method)

- Static steering effort
- Catch up
- Steering effort in slalom
- Steering returnability

Of the above, the evaluation items where sensory evaluation methods are prescribed as the basis for the steering feel evaluation (Fig. 1) can evaluate steering feel from a variety of perspectives, however there are no explanations such as the driving conditions for each evaluation item or definitions of the evaluation perspectives, and there was the issue of being largely dependent on the recognition of the evaluator.

Evaluation item		Score (10 point method)		Evaluation result/Notes
		Individual	Overall	
Steering effort, holding effort	At static steering			
	When driving			
Steering returnability	Low speed (up to 40 km/h)			
	Medium to high speed (over 40 km/h)			
Response	Static steering to low speed (up to 40 km/h)			
	Medium to high speed (over 40 km/h)			
Center feel	Clarity			
	Linearity			

Fig. 1 Examples of sensory evaluation items

Other quantitative evaluation methods conform to the vehicle steering characteristics evaluation methods prescribed by JASO and elsewhere³⁾, and evaluation of basic steering characteristics is possible. However, there are issues, including that the relationships with the items

in the JTEKT sensory evaluation sheet are not indicated, and that the perspectives are insufficient for evaluating the diverse range of EPS steering feel characteristics.

2. 2 Concept for Construction of a New Evaluation Method

In contrast with the previous evaluation method described in Section 2. 1, the policy for construction of a new evaluation method includes the following items.

- Organize the evaluation items and eliminate evaluation bias and omissions.
- Clearly define the purpose and definition of each evaluation item, allowing them to be shared among the developers.
- Visualize the relationship between the customer quality requirements, which is the true nature of sensory evaluations, and the quantitative indexes that serve as guidelines for performance design.
- Quantitative evaluation methods shall use test conditions that clearly identify differences in and the quality of steering feel.

In order to achieve the above, the evaluation methods and evaluation items are organized using quality function deployment as shown in Fig. 2. The required quality, quality factors, and quality characteristics that compose quality function deployment were respectively determined to be “the customer quality requirements (driver and occupants),” “sensory evaluation items,” and “quantitative evaluation methods and indexes.” As a result, it is possible to gain an overall view of the positioning and purpose of each evaluation, enabling

increasing performance development efficiency and continual process improvements.

3. Study of Sensory Evaluation Methods

3. 1 Customer Quality Requirements

Sensory evaluation methods convert the sense of the evaluator into numbers and words⁴⁾, however these are affected by the driving environment conditions at the time of the evaluation and by the awareness of the evaluation purpose. First, it is important to make clear the situations experienced by the drivers and occupants who are the customers while driving a vehicle, as well as the good or bad quality, and to organize the results and position them as the required quality. Required quality is divided into levels 1 to 3. Overall items are decided for Level 1, and then specific items are examined with consideration for feasibility in Level 2 and Level 3.

3. 2 Sensory Evaluation Items

For evaluations of steering feel, the steering functions and performance while driving a vehicle are identified and evaluated. Therefore, each evaluation is an item based on a function provided by steering.

As shown in Fig. 3, the review of sensory evaluation items organized the previous sensory evaluation items from the perspectives of the basic functions of the steering wheel, specifically “transmission of the steering amount (angle),” “transmission of force,” and “smooth operation” in order to identify evaluation areas that were lacking. Then the evaluation items necessary for satisfying the

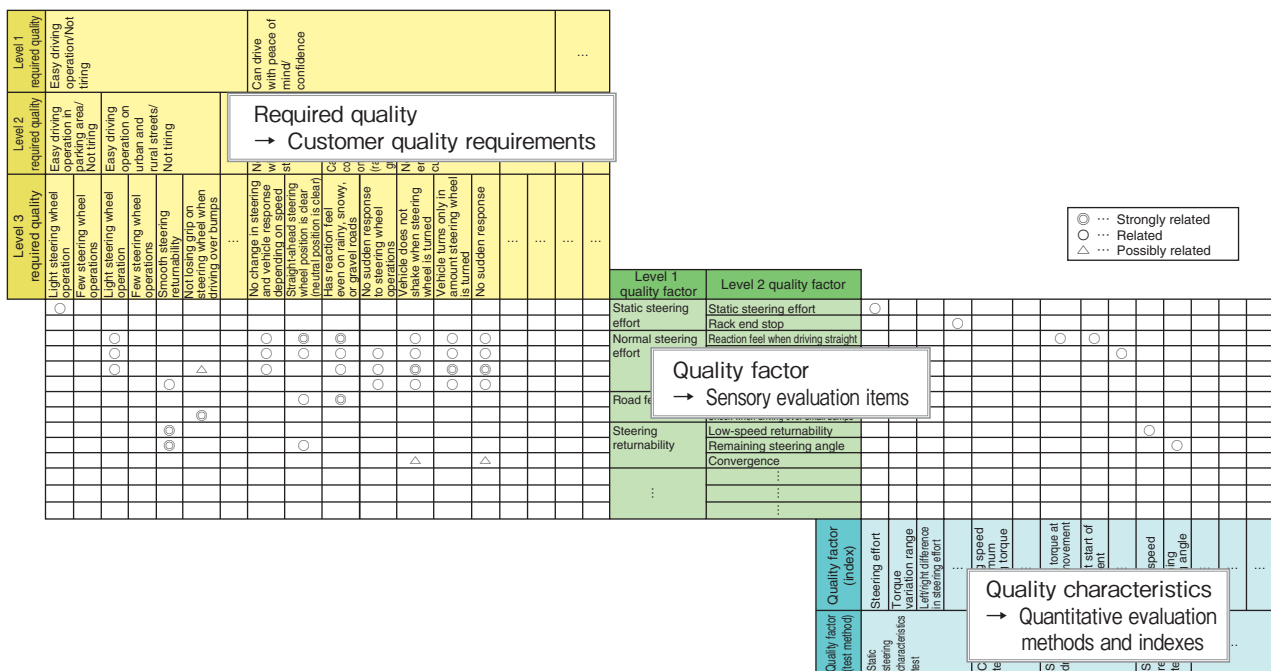


Fig. 2 Evaluation methods organized according to the quality function deployment method

required quality that was described in **Section 3.1** were added. By creating an explanation for each evaluation item of matters such as the driving conditions, steering conditions, and characteristics to focus on, we worked to facilitate sharing of the evaluation item definitions among the developers.

The sensory evaluation items decided in this way are positioned as the quality factors in the quality function deployment of **Fig. 2**.

Basic functions		Evaluation	
Level 1	Level 2	Level 3	
Steering wheel smoothness (Regardless of steering speed) (Regardless of driving situation) (Regardless of environmental conditions)	Smoothness of initial steering	Steering weight	
		N clarity (reaction feel when close to straight ahead)	
		Reaction feel	
		Linearity	
		Assist response (catch up)	
		Friction	
		Inertia feel	
		Viscosity	
		Stickiness (stick-slip)	
		Steering torque variation (torque ripple)	
		Shock at full steering	
	Ease of holding steering angle	Holding weight	
	Smoothness of return	Recoverability from full steering	
		Returnability (speed)	
		Returnability (remaining steering angle)	
	Steering convergence	(1) Steering wheel convergence	
		(2) Vehicle convergence	
		Balance of (1) and (2)	
Accuracy of steering transmission	Linearity of steering transmission	Response to minute steering	
		Linearity at steering wheel center	
		Precision of steering reversal	

Fig. 3 Determination of sensory evaluation items

4. Determination of Quantitative Evaluation Methods

This section describes the quantitative evaluation methods that are used for the quality characteristics in quality function deployment.

While sensory evaluation is an effective approach to product development, it is difficult to correctly associate the evaluation results with the target performance and design elements. In particular with EPS, where advanced control is now used, the number of design elements is extremely large and there are limits to what can be

communicated by qualitative terms. For this reason, it is necessary to quantitatively understand the physical phenomena that are linked to the sensory evaluation items, and it is important to establish quantitative evaluation methods.

4.1 Evaluation Conditions

With sensory evaluations, evaluations are performed in all kinds of driving situations. However, with quantitative evaluations, it is necessary to divide the driving situations into levels, and narrow them down to several representative driving conditions. When setting these conditions, for the sensory evaluation items described in **Section 3. 2**, we identified to the extent possible the steering patterns and steering amounts for actual evaluation by the driver. For this identification, in addition to acquiring and analyzing driving data, it was important to analyze the sensory evaluations themselves to determine how the driver perceives quality during steering.

Setting these quantitative evaluation conditions made it easier than before to clearly find differences and characteristics through relatively simple expressions of physical quantities, even for the steering feel of individual vehicles—something where finding differences was difficult with previous measurement data.

The items measured for quantitative evaluations include steering torque, steering wheel angle, steering speed, yaw rate, and lateral acceleration.

4.2 Quantitative Indexes

Graphing the data measured for each evaluation item produces a waveform such as that shown in **Fig. 4**. It is necessary to identify the part of this waveform which should be focused on in order to clearly express quality, and how the waveform can be viewed in order to correlate it with sensory results. While this requires verification using multiple evaluators and multiple vehicles, this process is not described in this report.

For example, **Fig. 4** shows the relationship between vehicle behavior and steering torque when the steering wheel is turned slowly while driving straight. For the related “reaction feel when driving straight” evaluation item, the steering torque at the moment when the vehicle begins to move and the slope after the moment when the vehicle begins to move are highly related to the sensory evaluation, and so we focused on these two points. Organizing these points of focus allows the data to be collected easily using indexes such as those shown in **Fig. 5**.

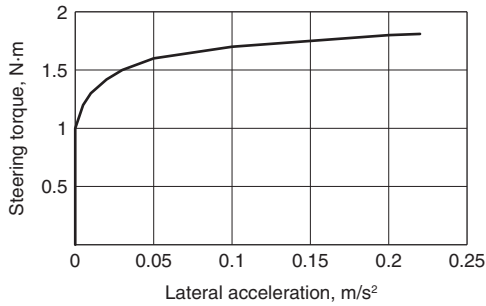


Fig. 4 Example of measurement data for straight driving

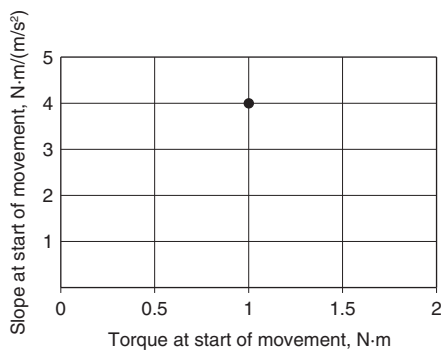


Fig. 5 Example of quantitative indexing

4.3 Target Performance

By plotting the measurement results of benchmark vehicles on the above quantitative indexes and identifying the area where the vehicles with high sensory evaluation scores are grouped, it is possible to determine the area for target performance as shown in Fig. 6. Based on sensory evaluation comments, a qualitative direction is also indicated, and this allows more detailed information to be identified.

By establishing quantitative indexes and target performance for other evaluation items in the same way, it is possible to decide and share the overall quality of steering performance.

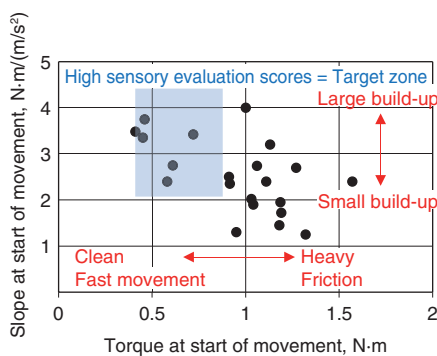


Fig. 6 Example of target performance

5. Application to Development and Future Outlook

Building steering performance in mass production development is most often led by the automobile manufacturers, however during the preliminary development stage, the relative role of performance studies and production by the steering supplier becomes larger. In order to propose new systems or functions to automobile manufacturers, vehicle performance studies and production are essential.

In these situations, new steering performance evaluation methods are being used effectively.

5.1 Steer-By-Wire (SBW) Steering Performance Evaluation

In an SBW system where the steering wheel and tires are not physically connected, the steering characteristics depend entirely upon the controls, and it is necessary to create them more deliberately. While the design freedom for steering characteristics is significantly improved, there is also the large possibility of an unfamiliar steering feel if they are not produced correctly. For this reason, it is all the more important to set clear target performance.

5.2 Application to Advanced Driving Assist System (ADAS) Evaluations

When research into ADAS first started, there was some discussion suggesting that the installation of ADAS would reduce the importance of steering performance. However now, when ADAS are actually in widespread use, it is clear that this is not the case. For example with lane keeping assist, the situation is very similar to the driver and ADAS gripping the same steering wheel in order to drive, and the characteristics affect the level of driver comfort. Performance evaluations of lane keeping assist functions and other ADAS functions are already being carried out by EURO NCAP, JNCAP, IIHS, and other institutions. While paying attention to these trends, we will study ADAS evaluation methods in the same way as the steering performance evaluation methods described above.

6. Conclusion

In steering system development, in order to develop products that provide a more comfortable and natural steering feel, we have reviewed and rebuilt our previous steering performance evaluation methods.

It seems that the construction and visualization of an evaluation system using quality function deployment will serve as a platform for further discussions of these evaluation methods, and we expect that continual improvements will be carried out in the future.

In addition, the newly created quantitative evaluation methods are already being effectively put to use in studies of steering performance in the development field. However at the present time, evaluations covering all aspects of steering feel are not being conducted, and there remains a dependence on sensory evaluation. In order to more efficiently produce higher-quality products, it will be necessary to correctly conduct evaluations of these aspects, and we intend to proceed with further expansion and construction of quantitative evaluation methods for this purpose.

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