1. Introduction

Vehicles equipped with ball screw type power steering system which had begun to be produced since the middle of 1970s required for improvement in driving stability in the 1980s. So that a great number of vehicles have undergone structural changes from rear-wheel drive systems to front-wheel drive systems since then. At the same time, steering systems also have been changed from ball screw types to rack & pinion types, thus allowing driving performance to be remarkably improved.

It is no doubt that each vehicle has been developed on the target of the same performance level as that of European vehicles, which practically have required steering systems so sophisticated as to be capable of comfortably driving at high vehicle speeds on high ways like "Autobahn" in Germany.

In the Japanese automobile market, the same high performance steering system has also been asked, which therefore has been much improved in terms of not only design but also manufacturing in response to the market demands.

Valve characteristics trends for recent rack & pinion type steering systems are described herein.

2. Technology Trends for Improvement of Steering Feeling

2.1 Steering Valve Characteristic

2.1.1 Electronically Controlled Pressure Reaction Chamber Type Power Steering System

The most important performance in power steering system is a valve characteristic that practically exerts a large effect on a steering feel. Directly perceived by vehicle drivers, this characteristic is regarded as a vehicle steering feel. In order for acquisition of optimal steering feel, various new technologies have been conceived and put into mass production. Among them, an electronically controlled power steering system, which is capable of actively controlling the steering feel, has been developed and is currently under mass production by Koyo.

The responsiveness of this system has been improved at high vehicle speeds and adopts a hydraulic reaction force control mechanism in association with its valve mechanism in order to provide such a stiffness similar to a manual steering system. Characterized by a steering feel with higher stiffness, it has been applied mostly for sport vehicles in Japan and in other countries.

Figure 1 shows its structure and Fig. 2 shows its valve characteristics.
2. 1. 2 Electronically Controlled Step-orifice Type Power Steering System

Furthermore, an electronically controlled step-orifice type power steering system has been developed and mass-produced for the purpose of smoother steering feel and insensitivity to friction.

Figure 3 shows a valve characteristic for this system.

![Figure 3](image)

**Fig. 3 Characteristics of step orifice type valve**

2. 1. 3 Improved-Characteristic Type Power Steering System

Recently, a structural review has been conducted to existing power steering systems for simplification and further natural steering feel, so that a great number of improved type power steering systems have been adopted in Japan, USA and Europe. Nowadays there are requests from car manufacturers for valve characteristic not only matching for each vehicle characteristic but also keeping high accuracy. In each country, power steering systems have the similar basic mechanisms and provide specific valve characteristic in response to particular requirements. This trend is favored by application of a sophisticated machining technology in higher accuracy to the valve mechanism. The following is a description of our process for such improvement.

3. Valve Mechanism with Double-stage Chamfer

3. 1 Steering Feel and Valve Characteristics

Table 1 shows a summary of valve characteristics in relation to vehicle requirements, required for procurement of a steering feel in conformity with a vehicle behavior.

<table>
<thead>
<tr>
<th>Vehicle requirements</th>
<th>Application to valve characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of neutral position (Neutral position definitely be identified at driving straight ahead and at steering operation)</td>
<td>Curve of pressure boost from slight steering zone (Improvement in identification of neutral zone at sudden assistance from dead band)</td>
</tr>
<tr>
<td>Smoothness of further steering operation (Linear steering feel obtained without sudden variation of steering effort)</td>
<td>Smooth pressure boost of valve characteristic curve (Smooth pressure boost without sudden variation in normal steering zone)</td>
</tr>
</tbody>
</table>

It has been confirmed that improvement of a valve characteristic improves a steering feel remarkably. It has also been proved that the improvement can be technologically achieved by accurately machining the control edges on valve which affect valve characteristics.

One of the technologies for this is a double-stage chamfering that is constituted by two processes of chamfering, in place of a simple-stage chamfering composed by conventional one process of chamfering.

3. 2 Valve Characteristic Obtained from Double-stage Chamfering

Figure 4 shows an improved valve characteristics and Fig. 5 shows a conventional valve characteristics (for an example).

![Figure 4](image)

**Fig. 4 Improved valve characteristics (Double-stage chamfering)**

![Figure 5](image)

**Fig. 5 Conventional valve characteristics (Simple-stage chamfering)**

Difference between the improved and conventional valve characteristics is represented by a characteristic curve line in low pressure zone (marked by circle) and this difference affects a steering feel at vehicle driving.

The followings are improvements as mentioned above:

- ○ : Improvement in smoothness of valve characteristic in normal use zone.
- ✡ : Improvement in sudden ramp-up from neutral zone of valve characteristic

3. 3 Mechanism of Characteristics Improvement

Double-stage chamfering on the control edge changes valve characteristics smoother than that created by single-stage chamfering, in zones from low pressure to middle pressure and from middle pressure to high pressure.
In addition, an adjustment of the first stage chamfering angle allows a sudden pressure boost to be damped at a transition from the dead band to the beginning of valve closing. Figure 6 shows a diagram of input angle vs valve orifice area for reference.

4. Further Improvement of Valve Characteristics

Valve characteristics of conforming to each vehicle originality could not only decrease an inharmonious steering feel but also provide a pleasure in vehicle driving. It also would be subjected to a further improvement and development in response to the possible requirements in the new epoch. In consequence, an optimal steering feel in harmony with each vehicle could be realized hereafter by a differentiation of valve characteristics currently still difficult to implement.

On the other hand, a recent environmental evolution in automobile industry has accelerated a mass production of ecological and energy-saving vehicles. Then, different types of electric motor driven power steering system have been produced for energy saving, among which is cited as an example an electric pump type hydraulic power steering system. Excellent in both energy saving and steering feel, this system would be one of new technologies to be expected hereafter. It also requires the above mentioned sophisticated valve control.

5. Conclusion

Various technologies for improvement in steering feel on vehicles are presented. In reality, needs in market for improvement in steering feel and driving stability have been more and more increasing, which are, needless to say, essential items inherent to vehicle performance for realization of steering reliability and sport features. Therefore, the steering feel and driving stability would become hereafter also a target of research and development.

Reference