1. Introduction

Cross joints, also known as Cardan joints, (see Fig. 8) have been used for automotive steering systems. Since a cross joint is not a constant velocity joint, if only one cross joint is used to provide a larger operating angle for an automotive steering system, then variation in rotational angle and resultant variation in torque occurs, leading to uncomfortable steering. To avoid this problem a feature similar to that obtained with constant velocity joints can be achieved if two joints are combined such that their operating angle is the same. They are positioned in rotational phases where the deviation in rotational velocity of one joint is counterbalanced by the other joint.

With recent automotive models, the available space in engine compartments is becoming smaller and smaller due to the conflicting needs for both compact, lightweight car bodies and greater passenger space. As a result, there has been increased difficulty in realizing two-joint system steering layouts that provide constant velocity features.

Using our expertise with constant velocity joints that have performed outstandingly with automotive drive shafts and in unique constructions, NTN has become the first in the world to develop a CSJ constant velocity ball-type steering joint that is capable of smooth, constant velocity actuation over the entire operating range. This report describes the features of our CSJ and the results of basic functionality tests.

2. Conventional technology

Steering joints are expected to operate smoothly and free from backlash in the rotational direction, while greater operating angles and compactness are desired. Currently double Cardan joints (D-CJ) (see Fig. 9) are mass-produced as constant velocity steering joints that consist of two cross joints with a centering mechanism so that one D-CJ unit can function as a constant velocity joint. However, the double Cardan joints have problems including greater size, heavier weight and low torsional rigidity. D-CJs can be categorized into two types: pseudo constant velocity steering joints that consist of two cross joints with a centering mechanism so that one D-CJ unit can function as a constant velocity joint. However, the double Cardan joints have problems including greater size, heavier weight and low torsional rigidity. D-CJs can be categorized into two types: pseudo constant velocity and full constant velocity. Both types have drawbacks, including unreliable constant velocity with angles outside the preset operation angle range and a narrower oscillating angle (see Table 1).
3. CSJ structure

The basic structure of the CSJ resembles that of the BJ (fixed constant velocity joint of track offset type) that is often used for drive shafts. However, with an ordinary BJ, clearance between the ball groove (formed between the outer race and inner race) and the balls is small, and as a result, backlash occurs in the rotational direction. Because of this, the BJ is not suitable for automotive steering systems that need to be free from backlash. Another problem is that if a tightening allowance is provided for clearance between the ball groove and the balls in order to reduce backlash, assembly of the BJ into the steering system may not be possible.

To solve these conflicting problems, we have added a plunger and a spherical plate to the joint (see Fig. 1). More specifically, a plunger comprised of a spring and a ball is provided at the shaft end, and the force of this spring is applied through the ball to the spherical plate fitted into the cage. As a result, as shown in Fig. 2, the inner race alone shifts to the right, causing the ball to be lifted until it touches the outer race, thereby the clearance on the ball groove is reduced.

With this structural arrangement, even when minor wear occurs on contact areas between the components due to extended steering system use, associated clearances are automatically reduced through the action of the spring, maintaining the steering system in a backlash-free state.

NTN has also attempted to optimize the shapes of the components and the clearance between them, and have optimized the force of the spring accordingly. In this way, we have achieved both reduction in rotational backlash throughout the operating angle range and smoother steering system rotational motion.

4. Performance characteristics

4.1 Rotational backlash

The results of comparison of our CSJ with a D-CJ are illustrated in Fig. 3.

Since it is free from excessive backlash, our CSJ boasts higher torsional rigidity, compared to currently used double Cardan joints (D-CJ), for automotive steering systems.
4.2 Rotational torque

The results of the comparison of the CSJ and the D-CJ are summarized in Fig. 4.

Though somewhat greater than that of the D-CJ, the rotational torque of the CSJ falls in a permissible range and has less variation. Therefore, these CSJ characteristics are suitable for steering joints.

5. Endurance and strength

The results of an endurance test are summarized in Fig. 5, and the results of strength tests are plotted in Figs. 6 and 7.

In terms of both endurance and strength, the CSJ satisfies targeted levels, and we believe that the CSJ can be used in applications on actual automobiles.

6. Comparison with other constant velocity steering joints

Compared with competitors’ double Cardan joints, the CSJ is lighter and more compact, and has a greater permissible operating angle. Therefore, the CSJ can greatly improve the freedom of layout for automotive steering systems.

Table 1 Comparison of constant velocity steering joint

<table>
<thead>
<tr>
<th></th>
<th>CSJ</th>
<th>Double Cardan joint from competitor A</th>
<th>Double Cardan joint from competitor B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside dia.</td>
<td>∅ 64 mm</td>
<td>∅ 61.5 mm</td>
<td>∅ 70 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>441 g</td>
<td>970 g</td>
<td>830 g</td>
</tr>
<tr>
<td>Volume occupied</td>
<td>160 cm³</td>
<td>327 cm³</td>
<td>270 cm³</td>
</tr>
<tr>
<td>Operating angle</td>
<td>0°–48 deg (Fully constant velocity over whole range)</td>
<td>0°–47 deg (Pseudo constant velocity type)</td>
<td>40°–48 deg (Fully constant velocity type)</td>
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</table>

*Constant velocity feature is lost when the angle is outside the permissible range.*
7. Conclusion

Developed as a dedicated constant velocity steering joint for automobiles, the NTN CSJ is characterized by a unique preload applying mechanism incorporated into the joint and internal clearance optimized to realize not only inhibition of rotary-direction backlash but also the capability for smooth rotational operation over the entire operating angle up to the maximum operating angle of 48 degrees. These features, which are lacking in conventional BJs, make the CSJ capable of providing an ideal constant velocity for automotive steering systems, while maintaining sufficient endurance and mechanical strength.

With the CSJ, one joint unit provides smooth, constant velocity transmission of rotation, adjustment of joint angles and phase matching in the rotational direction. In contrast, two Cardan joints are needed for this application. Furthermore, compared with double Cardan joint arrangements, the CSJ features lighter weight and a more compact design, allowing significantly greater freedom for steering system design layout. We believe that our CSJ is the constant velocity joint type that can satisfy mounting needs for advanced functionality and more compact size in automotive steering systems.

Reference