Fixed Constant Velocity Joint with Ultra High Angle and High Efficiency “CFJ-W”

In the future, it is increasingly required to improve the energy efficiency of automotive parts and the added value of automobiles. So, by applying NTN’s proprietary technology, we have developed the fixed constant velocity joint “CFJ-W” with the highest maximum working angle and high efficiency in the world.

1. Introduction

In 2015, parties agreed via the Paris Agreement, to maintain the average global temperature rise attributed to greenhouse gas emissions from human activities, to below 2 degrees Celsius. Automobiles account for approx. 18% of the CO₂ emissions of energy origin, and therefore, energy efficiency improvement of automotive components is an urgent issue.

At the same time, longer wheelbases for larger passenger compartments, and larger size tires for driving stability, have become the vehicle trend. These trends affect the vehicle’s minimum turning radius and require a larger wheel angle in order to maintain the same turning radius of conventional vehicles.

The wheel angle is determined by vehicle design restrictions and the maximum bending angle (hereafter, “maximum working angle”) of the fixed type constant velocity joint (hereafter, “fixed type CVJ”) installed on the tire side.

In this article, the fixed type CVJ, “CFJ-W”, is introduced. The CFJ-W has the world's highest level of both efficiency and working angle and can contribute to the reduction of CO₂ emissions, deliver larger passenger compartments and increase vehicle driving stability.

2. About the Driveshaft

The driveshaft is a component that smoothly transmits engine power (both rotation and torque), to the tires at constant speed, even when the input shaft (differential gear shaft) and the output shaft (wheel shaft) are rotated at an angle. In general, the driveshaft consists of a fixed type CVJ, a sliding type CVJ, and a shaft to connect them together (Fig. 1). The fixed type CVJ can have a large working angle, but cannot slide in the axial direction; the sliding type CVJ has a small working angle, but allows for movement in the axial direction.

In 1997, ahead of the competition, NTN developed the “EBJ (with a maximum working angle of 47°)”, a light, compact and highly efficient joint. Then in 2012, for a light, compact, wide-angle, fixed type CVJ, NTN started production of the “VUJ (with a maximum working angle of 50°)”. Also in 2012, NTN introduced the “CFJ (with a maximum working angle of 47°)”, which through NTN proprietary design, reduced torque loss by half in comparison to NTN’s EBJ. As such, NTN has shown a track record of improving on joint efficiencies and widening angles.

3. CFJ-W Structure and Features

3.1 Structure

The CFJ-W basically follows the structure of the existing already developed CFJ; it consists of an inner race and an outer race, both of which have raceway grooves (hereafter, “tracks”) for the 8 balls that transmit running torque, a cage that holds the balls and a boot that can operate to the maximum working angle of 55° (Fig. 2).
3.2 Features

Adopting NTN’s proprietary spherical cross groove structure technology (Fig. 3) made it possible to reduce the force generated within CVJ (internal force) upon torque load, as well as to increase the load carrying capacity. This enabled smooth operation of the CVJ internal components, even under tough operating conditions. Additionally, applying NTN’s technology helped the CFJ-W achieve the world’s largest maximum working angle and transmission efficiency, while maintaining an outer race diameter and weight similar to a conventional high-angle fixed type CVJ (i.e. VUJ). (Table 1 and Fig. 4)

To ensure quality, the associated boot shape was redesigned to withstand the wider CFJ-W angle, while maintaining outer race diameter dimensions that are equivalent to those of conventional boots.

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**Table 1** Comparison of VUJ and CFJ-W

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional Product VUJ92</th>
<th>Developed Product CFJ92W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Working Angle (°)</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Outer Race Outer Diameter mm</td>
<td>Φ87.8</td>
<td>Φ88</td>
</tr>
<tr>
<td>Number of Balls</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Ball Diameter mm</td>
<td>Φ17.462</td>
<td>Φ15.081</td>
</tr>
<tr>
<td>Weight kg</td>
<td>1.64</td>
<td>1.60</td>
</tr>
<tr>
<td>Torque Loss</td>
<td>–</td>
<td>Over 50% reduction</td>
</tr>
</tbody>
</table>

**Fig. 3** Spherical cross groove structure

Feature 1: The arc-shaped tracks of the inner and outer rings are tilted in the axial direction, and adjacent tracks are mirrored.
Feature 2: The inner track and the outer track cross the slope of each other, and the ball is placed at the intersection.

**Fig. 4** Appearance of VUJ and CFJ-W
3.3 Achieving High Efficiency & a Large Maximum Working Angle (50 Degrees-Plus)

Within conventional joint (i.e. EBJs, VUJs) structures, the ball tracks on the inner and outer race are formed in an arc shape (shown in Fig. 5), with the arc centers offset in opposite directions from each other from the center of the joint. On the other hand, the CFJ-W inner and outer races’ arc-shaped track centers are not offset, but slanted in the axial direction, with adjacent tracks symmetrically placed with the angles of the inner and outer race tracks crossing each other (shown in Fig. 6). This ensures the functionality of the CVJ and greatly contributes to the achievement of both a large maximum working angle (working angle of over 50 degrees) and high efficiency.

1) CVJ Internal Force

As mentioned above, the CFJ-W has adjacent arc-shaped tracks axially inclined and placed symmetrically relative to each other. The intended affect for this design is to have the adjacent balls push the cage in opposite directions, canceling out the resultant forces that suppress the axial displacement of the cage (shown in Fig. 6). This significantly reduces the spherical contact force between the cage and outer race, and between the cage and inner race, which greatly improves torque loss ratio.

Also, it is known that as the CVJ working angle increases, the load produced inside the CVJ increases independent of torque input⁴. Along with this increased load, the load on the CVJ internal components also increases resulting in increased heat and degraded strength. At the high working angle range, the CFJ-W's spherical cross groove structure reduces the contact force produced inside the CVJ. As evidenced by the spherical contact force analysis in Fig. 7, the aforementioned structure nearly eliminates the contact force in the normal operating range. Even at the high working angle range, close to the maximum working angle, the contact force is reduced in comparison to that of the conventional product, contributing to the achievement of functionality in the range beyond 50 degrees.

2) Load Carrying Capacity

For achieving a maximum working angle beyond 50 degrees, it is important to control deformation of the internal components. Internal component deformation is mainly a product of ball and track contact at high working angles and high torque inputs. Therefore, it is necessary to keep sufficient track depth at the high working angle range. The CFJ-W’s spherical cross groove structure positions the CFJ-W inner and outer races’ arc-shaped track center in the same plane as the center of the joint which ensures the same track depth at any range (Fig. 8 hatched area), improving the load carrying capacity of the CFJ-W at the high
working angle range. This differs from that of the conventional joint which has the inherent problem of reduced track depth at the high working angle range.

3) Grease

NTN has developed various high-functional greases used selectively in various CVJ types and applications. In order to achieve a 50-plus degree maximum working angle and high efficiency, internal force reduction as well as lubrication improvement is required.

By optimizing the thickener and additive, which resulted in outstanding grease fluidity and lower friction respectively, the CFJ-W grease reduced the friction coefficient in the SRV (vibration/friction/wear) test, as shown in Fig. 9. In the Torque Loss Test (Fig. 9) for an EBJ (conventional joint), this grease showed a 22% improvement in performance in comparison to the general-purpose grease’s performance in the same test. This supports that this grease’s use in a CFJ-W, can further reduce torque loss and heat generation.

4) Functional Evaluation

The results of the CFJ-W (developed joint) and VUJ (conventional joint) dynamic high-angle torsional strength evaluation, transmission efficiency (torque loss rate) evaluation and temperature rise characteristics (joint surface temperature) are shown in Fig. 10, Fig. 11 and Fig. 12, respectively of the developed product, CFJ-W, and the conventional product, VUJ, are shown in Fig. 10, Fig. 11 and Fig. 12, respectively.

At high angles, close to the maximum working angle, the CFJ-W and VUJ show equivalent strength. Transmission efficiency evaluation confirmed similar performances between the CFJ-W and the current high-efficiency fixed type CVJ, the CFJ; the torque loss was reduced by over 50% at any angle range in comparison to the VUJ (the current high-angle fixed type CVJ). Additionally, the temperature rise characteristics comparison show a 55% joint surface temperature reduction between the CFJ-W and CFJ.

These results show that the CFJ-W has the world’s highest level of efficiency in its normal operating range, as well as low temperature rise and sufficient strength at the severe operating conditions of working angles over 50 degrees.
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Fig. 10 Comparison of high-angle torsional strengths

Fig. 11 Comparison of torque loss rates

Fig. 12 Comparison of joint surface temperatures

4. Development of CFJ-W Dedicated Resin Boot

Since this joint achieved the maximum working angle of 55 degrees, which is the world’s greatest for vehicles’ front driveshafts, the boot applied also had to match this capability. This boot would be required to withstand angles higher than that of a conventional high-angle boot (for 50 degrees) and demanded boot shape improvements.

The CFJ-W boot needed to achieve the ultra-high working angle, while meeting the same functional and performance requirements of other fixed type CVJs, specifically the following items:

1. Durability and Sealability: equivalent to the conventional joint
2. Compactness: equivalent to the conventional joint
3. No clamp interference: no clamp interference at the maximum angle

4.1 Durability

An appropriate boot bellow length is required to ensure boot durability. There are different approaches to accomplish this, such as increasing the number of convolutes, increasing the boot large diameter and decreasing the boot small diameter. However, each of these techniques brings unfavorable consequences such as:

1. Increasing vehicle space needed for boot packaging and installation
2. Decreasing boot flexibility
3. Increasing the friction between adjacent boot convolutes
4. Increasing the chance of interference of the small diameter inner convolute with the IC shaft
5. Increasing the axial load on the clamp when the boot bellows are retracted

The boot developed for the CFJ-W addressed all the aforementioned issues through the addition of multiple, smaller multiple convolutes on both ends of the boot with these convolutes the same size as those used by conventional boots (as indicated by the circles in Fig. 13). In addition, to protect against friction at larger working angles, when considering the increased contact surface pressure between convolutes, a suitable material was selected. As a result, this boot achieved comparable durability to conventional boots.
4.2 Clamp Compactness and Interference Control

CVJ boots are designed considering interference with the joint and peripheral components, in addition to needing to be flexible at higher working angles. The bellow of the CFJ-W boot was designed with the optimum ratio of large and small diameter convolutes to achieve a small packaging requirement, even at high angle operations. Also, this design, while allowing the bellow to be convoluted on the outer diameter of the outer race, including the addition of the small convolutes with no clamp interference, protects the boot from being damaged by the clamp (as shown in Fig. 14).

5. Conclusion

In this article, the features and performance of “CFJ-W” were introduced; the CFJ-W achieves both the “world’s highest maximum working angle of 55 degrees” and “reduction of approx. 50% of torque loss rate in comparison to the conventional CVJ (VUJ)” by improving the load carrying capacity of each component and enhancing lubrication of NTN’s proprietary “CFJ” product, which was announced in 2012.

This developed product can be applied to the front wheels of 4-wheel drive vehicles, while achieving the same minimum turning radius as the rear wheel drive vehicles, as well as to reduce the adverse impact on fuel consumption due to increase of vehicle weight.

NTN hopes to introduce this product globally as the world’s benchmark for fixed type CVJs, achieving both high functionality and low CO₂ emission which are becoming increasingly required for vehicles globally.

References

1) IEA, CO₂ emissions from fuel combustion,(2018).
4) Yoshihiko Hayama, Dynamic Analysis of Forces Generated on Internal Parts for Ball Type Constant Velocity Joint, NTN TECHNICAL REVIEW, No. 70, (2002) 36-43.