1. Introduction

Recently, environmental concerns such as global warming have been highlighted globally. For reducing CO₂ emissions, which is the main factor of global warming, auto manufacturers are working on various aspects to reduce fuel consumption.

Under these circumstances, reducing weight and improving torque transmission efficiency are required, for lower fuel consumption, to the Constant Velocity Joint (hereafter, CVJ), which is a component to transmit the vehicle power.

The power from the vehicle engine is transmitted to the tires through the transmission, differential and driveshaft. The CVJ is used to smoothly transmit torque at the same rotational speed when the input and output of the driveshaft rotate at an arbitrary work angle. As shown in Fig. 1, “the sliding type CVJ” which can slide in the axial direction is used on the differential side of the driveshaft and “the fixed type CVJ” which has a larger work angle is used on the tire side.

2. Market Trend/Need

The CVJ has contributed to solving challenges that automobiles face such as safety, environmental protection, low fuel consumption, and ride comfort.

Historically, the fixed CVJ was required for its reduced weight and compactness and then later addressed the increased efficiency requirement. The sliding CVJ was required for its low vibration characteristics and then later addressed the requirement of lightweight and compactness.

Improvements to the grease for CVJ lubrication, higher shaft strength and development of the lightweight E-series have greatly contributed to the above development requirements of CVJs and high efficiency, contributing to lower fuel consumption of vehicles.

3. History of Development of CVJ¹⁻³

3.1 Before Development of CVJ

Vehicles before the 1960s were mostly front engine/rear drive type where power was transmitted to the rear wheels through a rigid axle and a CVJ was not necessary. A CVJ was not necessary for the front wheels either, as they were used only for steering, not for driving.

3.2 Adoption of CVJ to Automobiles (in the 1960s)

In front wheel drive (FF) vehicles and 4-wheel drive (4WD) vehicles, the power is transmitted to the front wheels; therefore, a driveshaft to steer and transmit driving power became necessary. Initially, a cross joint (Cardan joint) was used for the driveshaft. However, since it was not a constant velocity joint, the cross joint produced vibration and noise while driving with a large work angle and steering stability during cornering was poor.
To solve these problems, the Weiss joint, and Double Cardan joint, etc. were developed as the pseudo constant velocity joint; however, their performance was not sufficient enough for the driveshaft of automobiles. Then, Hardy-Spicer in the UK developed the Birfield joint (BJ) which is a predecessor of the current CVJ for automobiles and NTN introduced that technology in their products. At that time, the sliding motion in the axial direction was absorbed by the slide spline installed on the shaft, but the sliding double offset joint (DOJ) developed by NTN provided smooth sliding. These CVJs were superior in performance and reliability, improving driving stability significantly, and contributed to the development of FF vehicles.

Fig. 2 shows the history of development of NTN’s lightweight, compact and highly efficient CVJ.

### 3.3 Application to FF vehicles (1963 -)

When automobile manufacturers started developing FF vehicles at full scale, NTN worked with Suzulight (Suzuki) to develop the BJ in 1963 and succeeded with volume production of CVJs for the first time in Japan. Then in 1965, the BJ+DOJ, which is the current driveshaft style, was first adopted by the Subaru 1000 model vehicle.

In the 1970s, various auto manufacturers introduced FF vehicles into the market. The second oil crisis of 1978 accelerated the adoption of FF vehicles and the demand for NTN’s CVJs expanded. In addition, NTN’s CVJs greatly contributed to the expansion of the front engine/rear drive (FR) vehicles, which introduced independent suspension, from the rigid axle style, for improved ride comfort and the development and expansion of 4WD vehicles.

### 3.4 Lightweight and Compactness (1990 -), E-Series

The manufacturing process of the outer ring of CVJs was changed to induction hardening using medium carbon steel rather than carburized steel to increase strength and reduce weight. Also, urea-based grease was developed to facilitate a long operating life. With these developments, in around 1992, NTN started providing driveshafts of one size smaller and lighter than the conventional products.

Furthermore, from around 1995, NTN started the next phase of development of fixed/sliding type CVJ for lightweight/compactness and from 1998, started market introduction of the E-Series CVJ. The E-Series CVJ (EBJ) which is the fixed type CVJ, was developed by reducing the ball size and increasing the number of balls from 6 to 8 in order to achieve lighter and smaller units, while maintaining the load carrying capacity equivalent to BJ. Along with this, the sliding type CVJ, “EDJ” was also developed by increasing the number of balls from 6 to 8.

The internal design of the roller type sliding TJ was

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### Table 1: History of Development of Constant Velocity Joints Aiming at Low Fuel Consumption

<table>
<thead>
<tr>
<th>Date</th>
<th>CVJ Production Quantity</th>
<th>Fixed type CVJ</th>
<th>Sliding type CVJ</th>
<th>Shaft Grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Shaft w/standard material</td>
</tr>
<tr>
<td>1980s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Lithium based grease</td>
</tr>
<tr>
<td>Early 1990s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Boron steel shaft</td>
</tr>
<tr>
<td>Late 1990s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Urea based grease</td>
</tr>
<tr>
<td>2000s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Hollow shaft</td>
</tr>
<tr>
<td>2010s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>Low friction (μ) grease</td>
</tr>
<tr>
<td>2020s</td>
<td>BJ RJ</td>
<td>BJ</td>
<td>DOJ</td>
<td>New CVJ</td>
</tr>
</tbody>
</table>

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* ( ) following the date indicates the corresponding paragraph in the document text
also improved at the same time to achieve a smaller unit without degrading strength from the inherent longer operating life than ball type, resulting in the development of "ETJ."

The transition of reduction of weight and size mentioned above is shown as a comparison with the size #87 fixed type BJ and sliding type TJ as the baseline (Fig. 3). The size #87 was downsized to size #82 by application of long-life grease and high-strength shaft and then further reduction equivalent to 2 sizes by introduction of E-Series. Compared to the initial volume production, the current product achieved 13% reduction in size and 23% reduction in weight for fixed type BJ and 12% reduction in size and 17% reduction in weight for sliding type TJ.

3.5 Low Vibration Driveshaft

Along with the development of automobiles, the need for comfort and quietness increased for improved ride comfort, which increased the demand for low vibration sliding type CVJ.

The first developed sliding type CVJ was the ball type DOJ which had large sliding resistance. In 1984, the sliding resistance was successfully reduced by the adoption of *RPCF cage which has a structure to allow a small amount of ball rolling in the axial direction to absorb small amplitude vibrations.

In 1983 the roller type tripod joint (TJ), which was a newly structured sliding CVJ, was developed. Because of its structure of rolling rollers, sliding resistance was significantly reduced compared to DOJ and its adoption by FF AT vehicles expanded due to issues with idling vibration.

Later, TJ was also improved and in 2002, low vibration sliding type CVJ "PTJ" was developed, which allowed rollers to roll smoothly, even in the high work angle range, by combining elliptical trunnion journal shape and roller cassette, for addressing further low vibration and low sliding resistance (Fig. 4). The history of the development of the sliding type CVJ reduced sliding resistance, which contributed to the reduction of vibration and fuel consumption of vehicles over time.

*RPCF cage: Cage with a structure to allow movement between the cage and inner ring by opening a gap in the axial direction between them, which allows a ball to roll by opening gap between the cage window and the ball.

3.6 Lightweight Shaft (Hollow Shaft)

The shaft is a component to transmit power, connecting the fixed type CVJ and the sliding type CVJ. After achieving reduction of weight by enhancing the strength of the material of the solid shaft, a hollow shaft was developed, which increased rigidity and reduced weight. Volume production of hollow shaft started from the 2000s.

The hollow pipe raw material shown in Fig. 5 was processed to have both ends squeezed so they can be inserted to the inner rings of a CVJ. Applying a hollow shaft achieved 20-30% reduction of weight compared with the conventional solid shaft with the same torsional stiffness.
3.7 Light and Compact Rear CVJ (R-Series)\(^9\)

Conventionally, commonly designed CVJs were used for the rear driveshaft of FR vehicles and front driveshaft of FF vehicles. However, since the rear driveshaft of FR vehicles does not require a high work angle, a light and compact R-Series CVJ was developed specifically for rear driveshafts, as shown in Fig. 6. Together with the adoption of the hollow shaft and compact boot with less grease, the R-Series accomplished approx. 30% weight reduction compared with the conventional product.

![Fig. 6 Structure of R-Series](image)

3.8 Development of High Efficiency Fixed Type CVJ (CFJ)\(^5\)

In 2013, a structure to reduce sliding resistance among the internal components of the fixed type CVJ was developed, as the current structure was causing increased friction loss and thus reduced transmission efficiency as the angle increased. “CFJ” shown in Fig. 7 places the adjacent arc-shaped tracks mirror-symmetrically, so that the forces that the balls push on the cage with are alternately directed to the open side of the outer ring and the opposite side. These forces have the same magnitude and opposite directions; therefore, they are canceled out resulting in reduced axial displacement of the cage. This design significantly reduces the contact force of the spherical parts between the cage and the outer ring, as well as between the cage and the inner ring. As a result, the torque loss rate against the EBJ improved by approx. 50% (work angle of 9 deg) achieving the world’s highest level of efficiency, contributing to low fuel consumption.

![Fig. 7 Structure of CFJ](image)

4. Future Development

Although electric vehicles (EVs) are gaining traction, which changes the driving method, the requirement for the driveshaft will stay the same. Therefore, we will continue developing light, compact, highly efficient and quiet CVJs while optimizing strength and durability suitable for the application, use and vehicle characteristics by anticipating the future trends and needs of vehicles.

5. Summary

In this article, the history of the development of the constant velocity joint (CVJ) for driveshaft, which was aimed for low fuel consumption, was reviewed. The performance of vehicles is constantly improving. The functional improvement of constant velocity joints directly and indirectly contribute to this vehicle performance, and therefore, NTN will continue developing and supplying CVJs that contribute to vehicle development and are friendly to the global environment.

References

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