Commentary

Evolution of Fixed Constant Velocity Joint that Contributes to Environmental Protection

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In 1963 **NTN** commercialized the constant velocity joint for the first time in Japan. Since then, **NTN** has continued to develop new products in order to adapt to the environmental policy which changes with the times. This article looks back on the evolution of **NTN**'s fixed constant velocity joints and explains about two types of high efficiency fixed constant velocity joints applied for the evolving EV market of the future.

1. Introduction

Drive shafts used for power transmission in automobiles can be divided into two types. Fixed constant velocity joints ("fixed CVJs") are attached to the tire side and can take a large angle as the tire rolls. Sliding constant velocity joints ("sliding CVJs") are attached to the powertrain unit side and can take an angle and slide with vertical movement of the vehicle body **(Fig. 1)**. **NTN** has been developing drive shafts that are compact, lightweight, high-angle, low-vibration, and has made continuous improvements using tribology, materials, mechanical design and other technologies. On the other hand, as abnormal weather conditions have occurred due to global warming caused by increased CO_2 emissions, the impact of human activity on the environment is being taken up as a social problem making it increasingly important to find a new approach to environmental conservation. Since the Kyoto Protocol was established in 1997, the international community has worked to advance global warming countermeasures. To achieve the global average temperature increase target set in the Paris Agreement of 2015, efforts to realize a decarbonized society by 2050 are accelerating around the world. Against that background, in recent years the use of high-efficiency (low heat generation) drive shafts has been attracting attention.

This paper focuses on fixed CVJs, for which there is a greater need for improvement from the market. We introduce the evolution of CVJs that **NTN** is continuously developing in response to the changes in automobiles associated with environmental protection.

2. Market trends/needs

As the drive toward decarbonization continues, each year countries around the world are tightening their standards for CO_2 emissions and fuel efficiency of automobiles. There is a continuing need for lightweighting and higher efficiency of all components used in automobiles. In addition, the automotive industry is rapidly shifting from conventional internal combustion engine vehicles to electric vehicles (EVs) which are expected to have a longer cruising range. In addition, changes in vehicle layout such as changes in the position of the powertrain unit and extension of the wheelbase are expected in order to provide space for large capacity batteries. **(Fig. 2)**

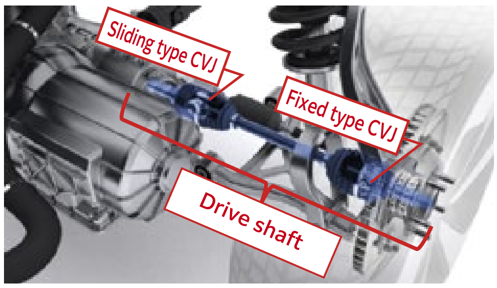

Fig. 1 Arrangement of fixed CVJs at the drive shaft

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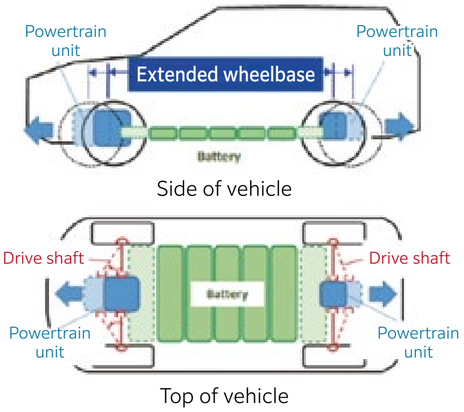


Fig. 2 Image of EV drive shaft arrangement

In this context, the functions required of drive shafts are (1) higher efficiency, smaller size, and lighter weight to help reduce fuel consumption and electricity costs, and (2) a higher operating angle (higher steering angle) to control the increase in turning radius due to an extended wheelbase and a higher working angle due to the need to secure battery space. One particular issue has been that fixed CVJs are less efficient than sliding CVJs in terms of the required functions and structure. **NTN** is continuously developing fixed CVJs to meet these market trends and needs.

3. Evolution of NTN fixed CVJs[1)2)4)5)]

3.1 Development of CVJs in Japan

Before the 1960s, automobiles developed mainly as rear-wheel drive (FR) vehicles, while front-wheel drive (FF) and four-wheel drive (4WD) vehicles were also developed to improve comfort and driving performance, etc. In FF and 4WD vehicles, power from the engine is transmitted to the front wheels. Drive components are therefore required to be able transmit power at constant speed even if the tires are steered. The cardan joint (cross shaft coupling, **Fig. 3**) used at that time was an unequal-velocity joint that caused large rotational fluctuations between the input and output shafts when the operating angle increased, resulting in unstable steering operation during driving.

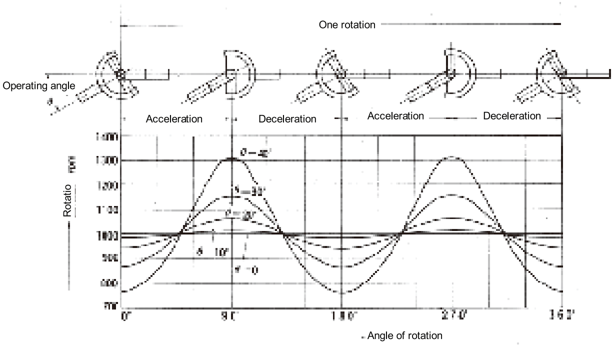


Fig. 3 Cardan Joint (cross shaft coupling)

In 1956, Hardy Spicer (U.K.) developed a fixed CVJ that could transmit power at constant velocity even when the operating angle was increased. This enabled the front wheels of a car to have both steering and driving functions. **NTN** formed a technology alliance with Hardy Spicer in 1962, through which we developed the BJ (maximum operating angle 42.5 degrees) for the Suzulight Van FE (Suzuki Motor Corp., **Fig. 4**). In 1964, the first vehicle equipped with a fixed CVJ that was successfully mass-produced in Japan was introduced to the market **(Fig. 5)**. This greatly improved handling stability, which had been a problem for FF and 4WD vehicles, and contributed greatly to the popularization of automobiles in Japan.

Later, to meet the rapidly expanding demand for fixed CVJs and the increasing need for higher steering angles in vehicles, **NTN** developed BJ-L **(Fig. 6)**, which expanded the maximum operating angle from 42.5 degrees to 46.5 degrees while maintaining the outer diameter. **NTN** achieved this by changing the fixed CVJ outer ring material from carburized steel to induction hardened midcarbon steel, and by making an optimal high angle design. Mass production of the BJ-L fixed CVJ began in 1982, is still used as the basic design today, and continues to evolve to capture the market needs of small size, lightweight, high efficiency, and high angle.

Fig. 4 Suzulight Van FE (Suzuki Motor Corp.)

Fig. 5 Exterior of CVJ mounted on Suzulight Van FE

Fig. 6 BJ-L exterior

3.2 The shift towards more compact, lightweight, high-efficiency CVJs

The evolution of fixed type CVJs is shown in **Fig. 7**.

The first evolution was to change the lubricant sealed inside the CVJ from lithium-based grease to urea-based grease, thereby achieving a longer operating life. The fixed CVJ (BJ-L compact) is 4 % smaller and 8 % lighter than the BJ-L while maintaining the maximum operating angle of 46.5 degrees. Mass production began in 1992.

The next evolution was the E-series fixed CVJ ("EBJ"; **Fig. 8**), which achieved further downsizing and weight reduction. To reduce the size while maintaining the same load carrying capacity as the BJ-L, the outer diameter size was reduced and the number of balls was increased from six to eight. The EBJ is 13 % smaller and 20 % lighter than the BJ-L, and it improved the torque loss ratio by 30 % (higher efficiency). Mass production of the EBJ began in 1998. The torque loss ratio was further improved by 20 % with the EBJ-S, by optimizing the internal clearance and applying low-friction grease to the EBJ. Mass production of the EBJ-S began in 2020.

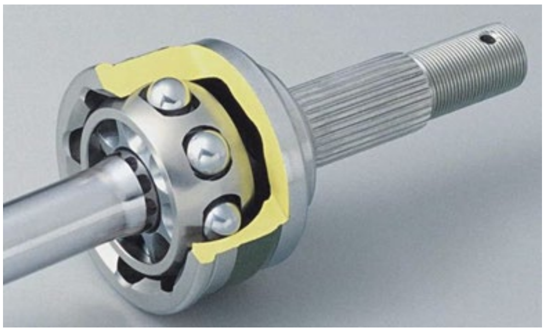


Fig. 8 Exterior of EBJ, EBJ-S

In 2022, **NTN** began mass production of the high-efficiency fixed CVJ "CFJ".[3)] This was the first CVJ to adopt **NTN**'s proprietary spherical cross groove structure (the "proprietary structure") as a further evolution of the EBJ. The same outer diameter and mass as the EBJ were maintained while the torque loss ratio was improved by more than 50 %. CFJs will be introduced in detail in Chapter 4.

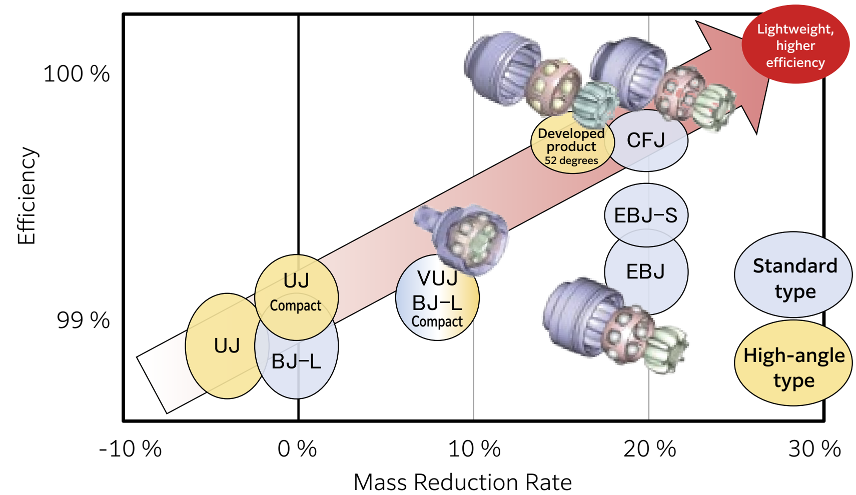
	Standard type					High-angle type			
	BJ-L	BJ-L compact	EBJ	EBJ-S	CFJ	UJ	UJ compact	VUJ	Developed product
No. of balls	6	6	8	8	8	6	6	6	8
Maximum operating angle	46.5 degrees	46.5 degrees	47 degrees	47 degrees	47 degrees	50 degrees	50 degrees	50 degrees	52 degrees
Start of mass production	1982	1992	1998	2020	2022	1988	1992	2007	—
Function									

Fig. 7 Evolution of fixed type CVJs

3.3 Increasing the operating angle of CVJs

As FF vehicles became larger in the 1980s and 4WD vehicles increased in number, the need to reduce the minimum turning radius drove demand for fixed CVJs with a high operating angle. In 1988, **NTN** began mass production of UJ, which has a maximum operating angle of 50 degrees. To ensure high angle functionality, mass production of UJ began with a 4 % increase in diameter and an 8 % increase in mass compared to BJ-L. In 1992, UJ (small size) was developed that achieved an outer diameter and mass equivalent to BJ-L by applying urea-based long-life grease **(Fig. 7)**.

In 2007, **NTN** began mass production of VUJ, which has the same six balls as UJ, but is smaller and lighter due to the optimized strength of each part and the application of long-life grease. In 2022, **NTN** completed basic development of a 52-degree high-angle fixed CVJ [developed product] based on CFJ technology. Compared to the UJs (compact type) developed since the 1990s, the VUJ is 4 % smaller and 8 % lighter, while the 52-degree high-angle fixed CVJ [developed product] is 10 % smaller and 16 % lighter, with a torque loss ratio improvement of over 50 % **(Fig. 7)**.

4. Helping to reduce environmental impact with higher efficiency fixed type CVJs

To meet vehicle requirements, **NTN** offers two types of fixed CVJs: a standard type and a high-angle type with different maximum operating angles, as shown in **Fig. 7**.

This chapter introduces the standard high-efficiency fixed CVJ "CFJ" and the high-angle type 52-degree fixed CVJ [developed product] to show how improvements in the efficiency of fixed CVJs can help to reduce environmental impact.

4.1 High-efficiency fixed CVJ "CFJ"[3] (standard type)

The CFJ is a fixed CVJ with a maximum operating angle of 47 degrees that achieves the world's highest level of efficiency through the adoption of a unique structure **(Fig. 9)** with the aim of reducing automobile CO_2 emissions and improving fuel efficiency. The torque loss ratio is reduced by 50 % or more while maintaining the same outer diameter and mass as the EBJ (conventional product), which has achieved the world's highest levels of compactness and lightweight.

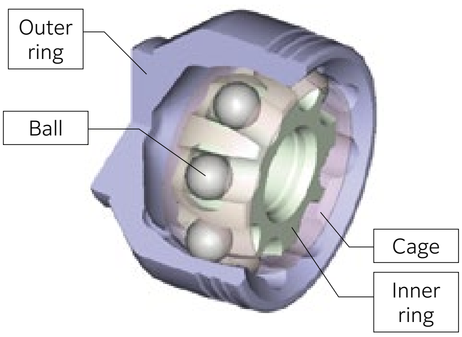


Fig. 9 Configuration of CFJ

4.1.1 Features

(1) Arc-shaped tracks on the inner and outer rings are inclined in the axial direction, with adjacent tracks arranged in mirror-image symmetry **(Fig. 10)**.

(2) The slopes of the inner and outer ring tracks cross each other and the ball is placed at the intersection **(Fig. 11)**.

The torque loss of a CVJ is equivalent to the energy lost due to the frictional forces that occur between the parts during torque transmission. In the case of EBJ, among the internal forces of the CVJ that occur during torque transmission, the direction of the force of the ball pushing the cage is the same for all balls. The cage is pushed in one direction and contacts the outer and inner rings. On the other hand, the unique structure of the CFJ causes the force of the ball pushing the cage to be in the opposite direction for adjacent balls, which cancels out the force on the cage and significantly reduces the contact force with the outer ring and inner ring **(Fig. 12)**. This reduces the frictional force between the cage and the outer and inner rings, resulting in the world's highest level of efficiency.

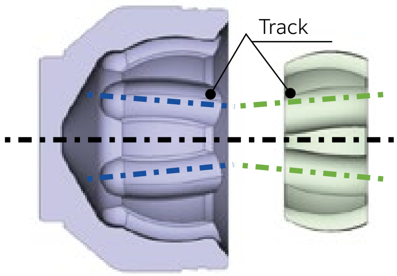


Fig. 10 Image of track shape

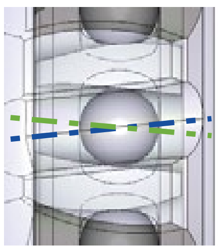


Fig. 11 Arrangement of track and ball

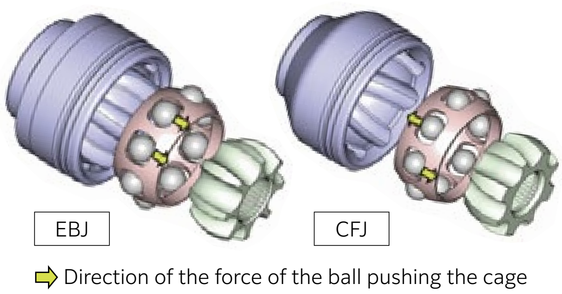


Fig. 12 Comparison of internal force

4.1.2 Function

Fig. 13 shows the measurement results of torque loss ratio. The torque loss ratio was reduced by more than 50 % compared to the conventional product not only during normal driving, but also during the regenerative driving that occurs in vehicles such as EVs.

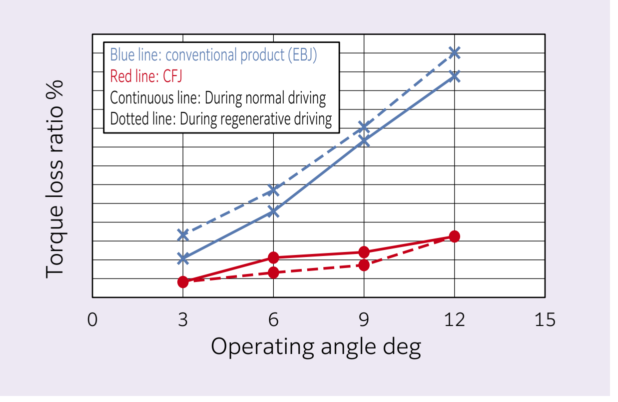


Fig. 13 Comparison of torque loss ratios

4.1.3 Efficiency of Fixed CVJs and Estimated Effects on Vehicles

The efficiency of the drive shaft, the component that transfers power from the engine to the tires, directly affects the fuel efficiency and electricity consumption of a vehicle. In addition, it has an even greater impact on hybrid vehicles and EVs that have regenerative braking for recovering energy during deceleration.

Performing a detailed calculation for CFJ, we find that in the case of a gasoline vehicle, fuel efficiency improves by 0.62 % and CO_2 emissions decrease by 0.96 g/km compared with EBJ (fuel efficiency: 17.6 km/L) when the vehicle weighs approximately 1.5 tons and the drive shaft is installed at a 9-degree angle under the WLTP (Worldwide Harmonized Light Vehicle Test Procedure) conditions. BEV (electric power consumption: 155 Wh/km) improves electric power consumption by 0.90 % **(Table 1)**.

Table 1 Effects on automobiles (EBJ ratios)

	Fuel and electricity cost Improvement rate	CO_2 Emission Reduction
Gasoline vehicle	0.62 % UP	-0.96 g/km
HEV	0.76 % UP	-1.12 g/km
BEV	0.90 % UP	—

<Test conditions>
Setting angle: 9 degrees
Vehicle: fuel efficiency 17.6 km/L; power consumption 155 Wh/km
Vehicle weight: approx. 1.5 tons; driving conditions: WLTP

4.2 52 degrees fixed type CVJ (high-angle type) [developed product]

This product is a high-angle, high-efficiency fixed CVJ. As well as offering a high operating angle that is larger than the maximum operating angle of the VUJ (maximum operating angle: 50 degrees), it offers high efficiency and is compact and lightweight.

4.2.1 Features

By adopting a unique structure similar to that of the CFJ, it is possible to reduce the force generated inside the CVJ during torque loading (internal force) and to improve the load carrying capacity at high operating angles. In addition, **NTN** changed the track shape in the area where the ball moves toward the outer ring aperture at high operating angles. This secured the rolling path length of the ball to align with the contact point between the ball and the track at operating angles exceeding 50 degrees. The cage, which is the weakest part of the fixed CVJ at high operating angles, was made smaller yet higher angle was achieved by optimizing the shape and changing the material. As a result, a 6 % reduction in size and an 8 % weight reduction were achieved while increasing the maximum operating angle by 2 degrees compared to the VUJ **(Fig. 14)**.

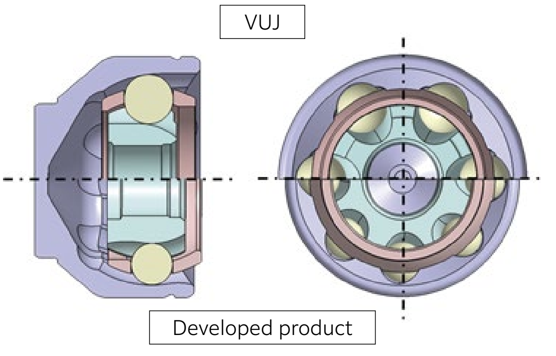


Fig. 14 Design comparison

4.2.2 Function

- Efficiency (torque loss ratio)

By adopting a unique structure, the torque loss ratio was improved by more than 50 % in all angular regions compared to the VUJ **(Fig. 15)**.

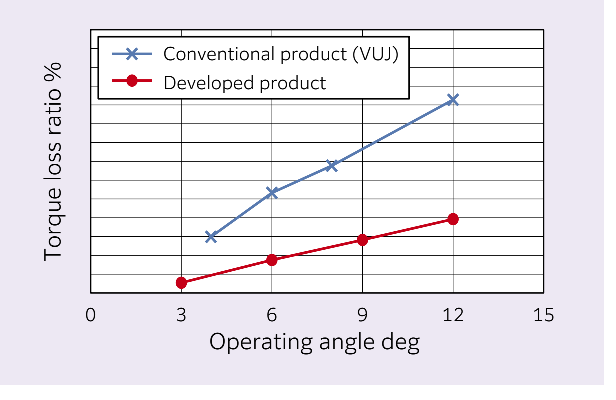


Fig. 15 Comparison of torque loss ratios

- Strength at high operating angles

By using a unique structure, modifying the track shape, optimizing the cage shape, and changing the materials, we achieved a 6 % reduction in size and 9 % reduction in weight compared to the VUJ, while achieving the same strength at high operating angles **(Fig. 16)**.

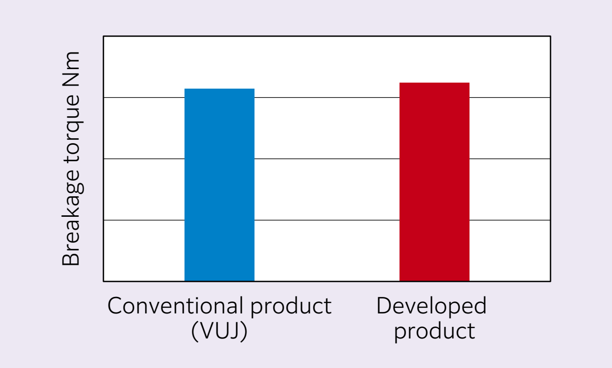


Fig. 16 High angle static torsional strength comparison

5. Summary

This paper touched on the evolution of fixed CVJs that contribute to reducing environmental impact, and introduced products **NTN** has developed in response to the changing times and their effectiveness. To realize a global decarbonized society, automobiles are undergoing a once-in-a-century transformation. CVJs are required to provide enhanced functions to respond flexibly to this transformation. As a constant velocity joint manufacturer, **NTN** will target demand for EVs, which will continue to expand going forward so that we can contribute to the realization of a decarbonized society and reduce environmental impact. We will continue to develop CVJs that are small, lightweight, high-performance, and have excellent quietness with optimal strength and durability tailored to the locations of their application and to vehicle characteristics.

References

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